University of Alberta

Establishment of Ambient Air Quality Trends in Edmonton and Fort McKay, Alberta

by

Kamran Faisal ©

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Abstract

Short-term changes (trends) in the concentration of various ambient pollutants – CO, NO_2, O_3, and $PM_{2.5}$ in Edmonton, Alberta and NO_2, O_3, $PM_{2.5}$, and THC in Fort McKay, Alberta – were examined over the last eight years. These changes were examined for concentrations and frequencies between the 50th and 98th percentiles of the concentration distributions of various pollutants for a calendar year. The relationships were assumed to be linear during the period of study and were fitted using simple linear regression. Hypothesis tests were conducted to identify whether slopes of the best fit lines were greater or less than zero.

For the city of Edmonton, NO_2 and O_3 did not show any statistically significant short-term trends over the period of study ($\alpha = 0.05$); however, statistically significant decreasing trends were observed for CO and $PM_{2.5}$ ($\alpha = 0.05$). All of the pollutants examined at Fort McKay – O_3, NO_2, $PM_{2.5}$, and THC – did not show any statistically significant trends over the period of study ($\alpha = 0.05$).

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LIST OF SYMBOLS

a	intercept
b	slope
e_{ijk}	error
i	year
j	season
mg/m^3	milligrams per meter cubed
M_j	effect for the season (j),
n	number of observations
n-1	degrees of freedom
ppb	parts per billion
ppm	parts per million
S	Mann-Kendall test statistic
T_i	effect for the year (i)
VAR	variance
xi	dependent variable (concentration or frequency)
$\hat{y}$	y estimated
Z	test statistic
α	significance level
μ	mean
$\mu g/m^3$	micrograms per meter cubed
σ^2_e	variance

LIST OF ABBRIVIATIONS

AAAQO	Alberta Ambient Air Quality Objectives
CASA	Clean Air Strategic Alliance
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CWS	Canada Wide Standard
HNO_3	Nitric acid
MMD	Maximum mixing depth
MSE	Mean Square Error
MSR	Mean Square Regression
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate
NO_X	Oxides of nitrogen
O_2	Oxygen
O_3	Ozone
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter $\leq 10\ \mu m > 2.5\ \mu m$
$PM_{2.5}$	Particulate matter with aerodynamic diameter $\leq 2.5\ \mu m$
SO_2	Sulfur dioxide
SO_X	Sulfur oxides

SSE	Sum of Squared Error
SST	Sum of Squared Total
SSR	Sum of Squared Regression
SSX	Standard Error of the Estimates
TEOM	Tapered Element Oscillating Microbalance
THC	Total Hydrocarbons
USEPA	United States Environmental Protection Agency
USNAAQS	United States National Ambient Air Quality Standards
VOC	Volatile organic compound
WHO	World Heath Organization

CHAPTER 1: INTRODUCTION

1.1 Air Pollution

Air pollution is referred to as the presence of any visible or invisible particles or gases in the air apart from the normal composition of air, causing adverse effects to humans and the environment (Weber, 1982). Air pollution is a worldwide problem and is considered to be a critical issue in most industrialized counties. Sources of air pollution can be natural or anthropogenic. Natural sources of air pollution include plant pollens, windblown dust, volcanic eruptions, and naturally generated forest fires (Byrne, 2000). Historically, in both industrialized and developing countries, the main man-made causes of air pollution have been the emissions of various gases resulting from the combustion of fossil fuels such as coal and oil for power generation (Al-Rashidi et al., 2005).

The level of air pollution in the atmosphere is affected by both emission sources and various meteorological conditions (e.g. atmospheric stability, topographic features, and temperature inversions) (Lyons and Scott, 1990). Air pollution can affect human and animal health, cause damage to the property, affect plant growth, and cause aesthetic problems (Byrne, 2000). Increased levels of air pollution can cause significant changes to the atmosphere, affecting all forms of life. These environmental effects have made it imperative for regulatory agencies to enforce strict regulations and promote efficient control technologies.

In order to understand whether changes in ambient air quality have occurred over time, monitoring and modeling are two basic techniques used by regulatory agencies (Memon, 2000). The purpose of air quality monitoring is to determine the status of, and understand the deviation from natural background levels and changes over time (trends) in selected measures of air quality in a monitored area. Air quality modeling provides a means of predicting and forecasting air quality in a specific area (Hasham, 1998). This information enables society to measure progress in achieving air quality goals and to maintain air quality guidelines and standards through analysis of past air quality behavior. Finally, this knowledge can be used as a basis for developing control strategies and tracking progress towards meeting guidelines and standards in areas where poor air quality exists.

1.2 Airshed Management Approach in Alberta

The overall air quality in Alberta is considered good most of the time; however, changes to air quality are an unavoidable consequence of population growth and an increase in industrial activities. Proactive approaches such as airshed management are the most promising to manage air quality so that it does not continue to deteriorate in the future (Kindzierski and Scotten, 2004). The main purpose of airshed management is to prevent any deterioration of air quality through active planning. In Alberta, air shed management is considered to be the best approach to manage the air quality as many of the Alberta's air quality issues are local in terms of their causes (CASA, 2004a). The establishment of air quality management zones provides an opportunity for local stakeholders to design local solutions to address air quality issues. The success of an airshed zone is largely dependent on the co-operation and dedication of all stakeholders, including governments, industries, environmental organizations, and the public.

One of the important aspects of air shed management is air quality monitoring which can take the form of specialized air quality studies conducted on a periodic basis and/or the development and operation of air quality monitoring networks. The main objective of an air monitoring network includes the following (Kindzierski and Scotten, 2004):

a) Collecting data in order to examine and evaluate overall air quality within an area covered by the network.

b) Assessing trends in air pollutant levels over several years.

Alberta Environment is working to promote broader monitoring coverage of air quality in Alberta by working with and encouraging the formation of airshed zones. Currently, there are six existing airshed zones operating under the Clean Air Strategic Alliance (CASA), as shown in Figure 1-1. These airshed zones are (CASA, 2004b)

- The Wood Buffalo Environmental Association Airshed
- The Peace Airshed Zone Association
- The Fort Air Partnership Airshed
- The West Central Airshed Society
- The Parkland Airshed Management Zone
- The Palliser Airshed Society

There are four contemplated airsheds (CASA, 2004b), including:

- Whitecourt-Swan Hills-Athabasca
- Lakeland Industry and Community Association
- Edmonton
- Bow Valley-Calgary

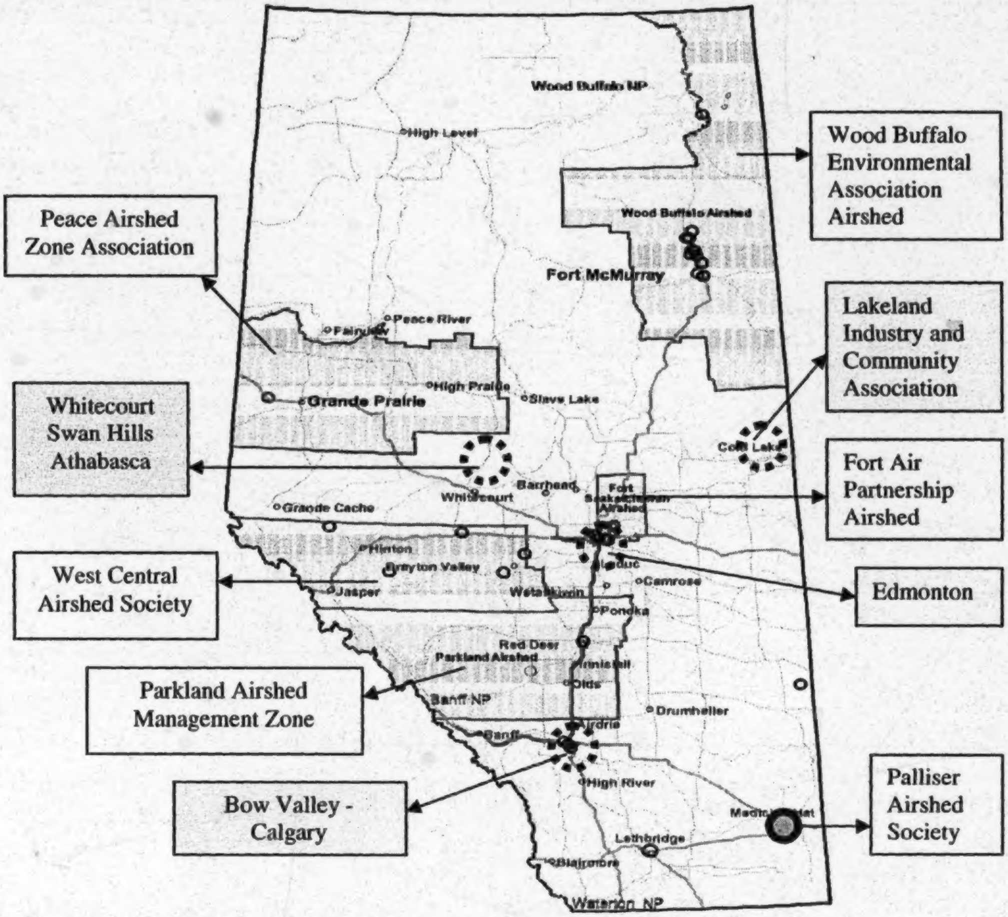
Wood Buffalo NP
High Level
Wood Buffalo Environmental Association Airshed
Peace Airshed Zone Association
Wood Buffalo Airshed
Fort McMurray
Fairview
Peace River
Lakeland Industry and Community Association
High Prairie
Grande Prairie
Slave Lake
Whitecourt Swan Hills Athabasca
Cold Lake
Fort Air Partnership Airshed
Barrhead
Whitecourt
Fort Saskatchewan Airshed
Grande Cache
Hinton
Drayton Valley
Leduc
West Central Airshed Society
Camrose
Edmonton
Jasper
Wetaskiwin
Ponoka
Red Deer
Parkland Airshed
Innisfail
Olds
Parkland Airshed Management Zone
Banff NP
Drumheller
Banff
Airdrie
High River
Palliser Airshed Society
Bow Valley - Calgary
Medicine Hat
Lethbridge
Blairmore
Waterton NP

Figure 1-1: Map of Alberta showing the six existing and four contemplated (in dotted circles) airshed zones (Adapted from CASA, 2004b)

Each airshed zone, in conjunction with Alberta Environment, has established a network of air monitoring stations within its boundaries. In the areas where airshed zones have not yet been established (e.g., Calgary or Edmonton) but which have large populations, Alberta Environment has its own air monitoring stations. In Alberta, Alberta Environment, individual air quality management zones, Environment Canada and industry operate a comprehensive network of nearly 140 air quality monitoring stations that measure ambient air quality (Alberta Environment, 2006a). Most of these air monitoring stations operate continuously 24 hours a day, 365 days a year. These air monitoring stations measure a variety of pollutants and meteorological factors in their respective areas.

This study focuses on the air quality analysis for the City of Edmonton and Fort McKay using trend analysis techniques. Historical ambient air monitoring data for O_3, NO_2, CO and $PM_{2.5}$ in Edmonton, Alberta and for O_3, NO_2, $PM_{2.5}$ and THC in Fort McKay, Alberta were analyzed to understand the changes in air quality over the last eight years. This analysis of air quality provides an indication of whether air quality in the area is changing for better or worse.

1.3 Objectives of the Study

The main objectives of this study are stated below:

- To study various trend analysis techniques in the literature.
- To examine any changes in the concentration of pollutants (CO, NO_2, O_3 and $PM_{2.5}$) in Edmonton, Alberta and (NO_2, O_3, $PM_{2.5}$ and THC) in Fort McKay, Alberta using the historical ambient air monitoring data.
- To illustrate a simple trend analysis procedure that can be used in future to assess the changes in air quality over the years.

1.4 Study Area

The City of Edmonton (less than a million people) is located in central Alberta (Figure 1-2) with 9,532 square kilometers of land area at an elevation of 679 m (CASA, 2006a). The city is bisected by the North Saskatchewan River, which originates at the

Columbia Icefield in Banff National Park. Major industries include petroleum refineries and chemical manufacturing facilities. Alberta Environment maintains a network of air monitoring stations in the city. The historical ambient air monitoring data for the selected pollutants for Edmonton were taken from the Edmonton Northwest station (a former air monitoring station which was located at 133 Avenue and 127 Street).

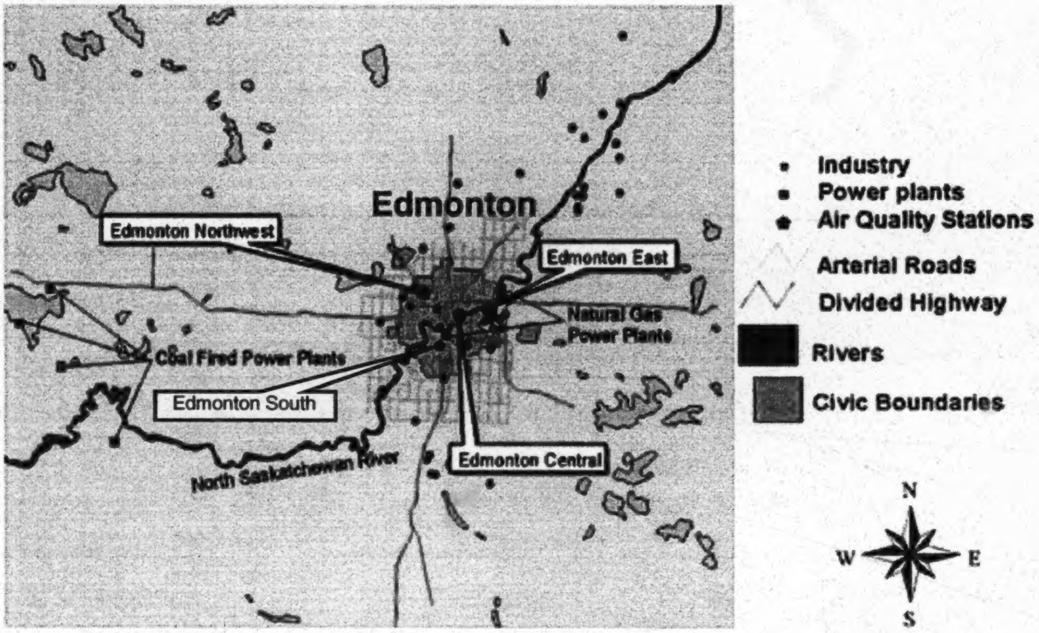
Edmonton
Edmonton Northwest
Edmonton East
Natural Gas Power Plants
Coal Fired Power Plants
Edmonton South
Edmonton Central
North Saskatchewan River
Industry
Power plants
Air Quality Stations
Arterial Roads
Divided Highway
Rivers
Civic Boundaries
N
W
E
S

Figure 1-2: Map of Edmonton showing the location of Edmonton Northwest air monitoring station

Fort McKay is a small community with fewer than 400 people and is located in northeast Alberta (Figure 1-3). It is situated among three large oil sand extraction and refining facilities. Prior to 2002, two of these facilities produced in excess of 500,000 barrels per day of synthetic oil. The third facility was commissioned in 2003, as a result of which, overall production of synthetic oil was estimated to rise to greater than 800,000 barrels per day. The proximity of these facilities has raised concerns among residents regarding air quality in the community. The historical ambient air monitoring data for the selected pollutants were taken from the Wood Buffalo Environmental Association Fort McKay station.

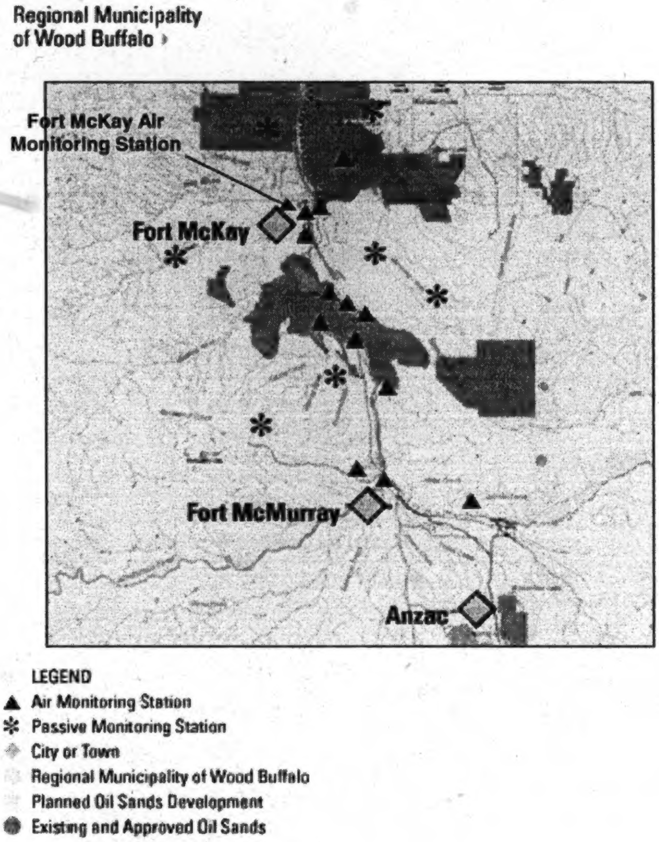
Regional Municipality of Wood Buffalo
Fort McKay Air Monitoring Station
Fort McKay
Fort McMurray
Anzac
LEGEND
▲ Air Monitoring Station
✻ Passive Monitoring Station
◆ City or Town
Regional Municipality of Wood Buffalo
Planned Oil Sands Development
● Existing and Approved Oil Sands

Figure 1-3. Map of the Regional Municipality of Wood Buffalo showing the location of Fort McKay air monitoring station

CHAPTER 2: LITERATURE REVIEW

Five different ambient air pollutants – CO, NO_2, O_3, $PM_{2.5}$ and THC – were selected for analysis in this study. Three of these pollutants – CO, NO_2, and THC – are emitted directly from a variety of natural and anthropogenic sources. Ozone is not directly emitted, but is formed when volatile organic compounds (VOCs) and nitrogen oxides (NO_X) react in the presence of sunlight (USEPA, 2006). $PM_{2.5}$ can be directly emitted, or it can be formed when emissions of sulfur oxides (SO_X), nitrogen oxides (NO_X), ammonia (NH_3), organic compounds, and other gases react in the atmosphere. All of these five pollutants are discussed in detail in the following sections.

2.1 Ozone (O_3)

2.1.1 Characteristics

Ozone is a colorless and reactive oxidant gas. At ground levels, it is a major contributor to atmospheric smog. Ozone has a characteristic sharp odour when it is highly concentrated, such as during lightning storms (Myrick and Hunt, 1998). Ozone is found both near the ground and in the upper atmosphere; it occurs naturally in the stratosphere and provides a protective layer high above the earth. Only ground level ozone is an air pollutant that affects human health and the environment.

2.1.2 Sources

Ozone is not emitted directly into the air but is formed by the reaction of volatile organic compounds (VOCs) and oxides of nitrogen (NO_X) in the presence of heat and sunlight (USEPA, 2004a). Ground-level ozone forms readily in the atmosphere, usually during hot, summer days. Intense sunlight can cause ground level ozone to form in harmful concentrations in the air. Day-to-day variability in O_3 concentrations depends heavily on day-to-day variations in meteorological conditions including temperature, solar radiation, and degree of mixing (USEPA, 1996). Changing weather patterns contribute to yearly differences in ozone concentrations from region to region. Ozone and the pollutants that form ozone can be transported to an area hundreds of miles away from the emission sources. The following simplified sequence outlines the formation of ozone from its precursors (Adapted from Environment Canada/Health Canada, 1999a).

$$2NO + O_2 \longrightarrow 2NO_2 \qquad [1]$$

$$NO_2 + \text{Short wave radiation} \longrightarrow NO + O \qquad [2]$$

$$O + O_2 + VOC_{(catalyst)} \longrightarrow O_3 + VOC_{(catalyst)} \qquad [3]$$

Both natural and anthropogenic sources can act as precursors to ozone formation. Some of the major sources of ozone precursors are vehicle and engine exhaust emissions from industrial facilities, combustion from electric power plants, gasoline vapors, chemical solvents, and biogenic emissions from natural sources (USEPA, 2004a).

2.1.3 Monitoring Methods

Ozone is monitored by either chemiluminescence or ultraviolet photometry processes (CASA, 2006b). The chemiluminescence process involves the reaction of an air sample with ethylene. The reaction of ethylene and ozone produces light. The intensity of the light produced is proportional to the ozone concentration. The ultraviolet photometry process uses a mercury vapor lamp as a source of ultraviolet radiation. This method determines the ozone concentration by the amount of ultraviolet radiation that is absorbed by the ozone in the sample (Myrick, 1995).

2.1.4 Human Health and Environmental Effects

Ambient ozone has a marked effect on the pulmonary function of human beings. Health effects attributed to ozone exposure include significant decreases in lung function, inflammation of the airways, and increased respiratory symptoms such as chest pain and cough (USEPA, 2004a). Exposure to ozone can make people more susceptible to respiratory infection for pre-existing respiratory diseases such as asthma. Short-term concentration spikes can cause irritation of the eyes, nose, and throat as well as chest discomfort (Hill, 2004). Longer-term exposure to moderate levels of ozone can increase the possibility of irreversible changes in the lung structure which could lead to premature aging of the lungs. In summer, the intense sunlight causes the ground level ozone to reach harmful concentrations in air, increasing the risk of ozone exposure for people who are active outdoors. Table 2-1 shows human symptoms and other health effects that result from exposure to various ozone concentrations.

Higher concentrations of ozone also affect vegetation and other aspects of the ecosystem. Agricultural and commercial forest yields can be affected by elevated ozone levels, leading to reduced growth and survivability of tree seedlings and increased plant susceptibility to disease, pests, and other environmental stresses (USEPA, 2004a). In species with long lives, these effects may become evident only after several years or even decades, thus having the potential for long-term effects on forest ecosystems. Ozone may also decrease plant resistance to bacteria, viruses, and insects, all of which can result in reduced plant growth and inhibited yields (Hasham, 1998).

Table 2-1: Human symptoms and other effects with specific O_3 concentration

O_3 Concentration	Exposure Time	Human symptoms and other effects
3 – 10 ppb (6 – 19 μg/m^3)	N/A	Low range at which an average person can smell ozone
20 – 40 ppb (39 – 78 μg/m^3)	N/A	Range in which ozone occurs in healthy outdoor environments.
150 ppb (293 μg/m^3)	N/A	For sensitive individuals, reduction in pulmonary lung function, chest discomfort, irritation of the respiratory tract, coughing, and wheezing
250 ppb (488 μg/m^3)	N/A	An increase in the incidence and severity of asthma attacks, moderate eye irritation
300 ppb (585 μg/m^3)	N/A	Headaches, chest discomfort sufficient to prevent completion of exercise, decrease in lung function in exercising subjects
500 ppb (975 μg/m^3)	N/A	Chest constriction, impaired carbon monoxide diffusions capacity, a decrease in lung function without exercise
1,000 ppb (1950 μg/m^3)	N/A	Coughing, extreme fatigue, lack of coordination, increased airway resistance, decreased forced expiratory volume
10,000 ppb (19500 μg/m^3)	N/A	Severe pulmonary edema, possible acute bronchiolitis, decreased blood pressure, rapid weak pulse

(adapted from PAS, 2006a)

2.1.5 Environmental Regulations

The guidelines for ozone levels are based on the prevention of adverse effects to human health and vegetation. A comparison of Alberta Environment ambient air quality guidelines with USEPA and WHO standards for ambient O_3 concentrations is presented in Table 2-2.

Table 2-2: AAAQO, USNAAQS and WHO Ambient Air Guidelines for O_3

Ground level O_3 Ambient Air Guidelines	**Concentration limits**	
	one-hour	**8-hour**
Alberta Ambient Air Quality Objectives (AAAQO)	82 ppb (160 μg/m^3)	65 ppb (127 μg/m^3)
US National Ambient Air Quality Standards (NAAQS) (Primary Standards)	120 ppb (235 μg/m^3)	80 ppb (157 μg/m^3)
WHO Ambient Air Quality Guidelines	N/A	60 ppb (117 μg/m^3)

(Source: Alberta Environment, 2006b; USEPA, 2001; WHO, 2006; CASA, 2006b)

2.2 Nitrogen Dioxide (NO_2)

2.2.1 Characteristics

Nitrogen dioxide is a reddish-brown gas with a characteristically pungent odor. It is partially responsible for the brown haze sometimes seen in urban areas. "Nitrogen oxides" (NO_X) is the term used to describe the sum of nitrogen dioxide (NO_2), nitric oxide (NO), and other oxides of nitrogen. In ambient air, NO_2 and NO are considered to be the most important forms of nitrogen oxides as they play a major role in the formation of ozone, particulate matter, haze, and acid rain (USEPA, 2002). Nitric oxide is a colorless and odorless gas and is the most prominent form of nitrogen oxide emitted at the source of emission (Hasham, 1998). High temperature combustion sources such as coal, gasoline, and oil generate NO. NO has no known health hazards; however, most of the NO in ambient air quickly turns into NO_2, which is considered a health hazard for humans. In the air, NO_2 is produced when NO gains an oxygen atom.

$$N_2 + O_2 + \text{heat} \longrightarrow 2NO \qquad [4]$$

$$2NO + O_2 \longrightarrow 2NO_2 \qquad [5]$$

(Adapted from Legge et al., 1980)

2.2.2 Sources

Oxides of nitrogen (including NO) are emitted both from natural and human activities. Natural activities that form NO_2 include anaerobic biological processes in soil, lightning, volcanic activity, and the photochemical destruction of nitrogen compounds in the upper atmosphere. Human activities that lead to NO_2 formation occur during combustion processes when oxygen and nitrogen combine at temperatures generally greater than 1000°C (Elsom, 1992). Almost every combustion source will emit nitrogen dioxide (including power plants, chemical plants, vehicles, furnaces, gas stoves, heaters, etc.). Motor vehicles account for more than 50% of anthropogenic NO_2 emissions in urban areas (PAS, 2006b).

2.2.3 Monitoring Methods

Oxides of nitrogen are measured by the principle of chemiluminescence (CASA, 2005c). In this method, an air sample is split into two pathways. In the first pathway, the NO concentration is measured by mixing ozone with the sample and detecting the amount of visible light produced when NO reacts with O_3 to form NO_2. The amount of light detected is proportional to the NO concentration and is a measurement of NO in the sampled air (CASA, 2006c). In the second pathway, all the NO_2 in the sample is reduced to NO by a catalytic converter, adding to the NO already present. The difference between the two readings is the concentration of NO_2.

2.2.4 Human Health and Environmental Effects

NO_2 has adverse effects on both human and environmental health. Human health effects associated with exposure to NO_2 are mainly related to pulmonary function. Direct exposure to NO_2 gas irritates the lungs, aggravates asthma, and lowers resistance to infection. Short-term exposures (e.g., less than 3 hours) to low levels of NO_2 can change the responsiveness of the airways and thus can affect the lungs' function in individuals with pre-existing respiratory illnesses (USEPA, 2002). Long-term exposures to NO_2 may increase susceptibility to respiratory infection and may cause irreversible alterations in lung structure. Table 2-3 shows human symptoms and other health effects resulting from exposure to various NO_2 concentrations.

Table 2-3: Human symptoms and other effects with specific NO_2 concentrations

NO_2 Concentration	Exposure Time	Human symptoms and other effects
2,500 ppb (4717 μg/m^3)	2 hours	Increased airway resistance in healthy adults
5,000 ppb (9434 μg/m^3)	15 min	Impairment of normal transport of gases between the blood and lungs in healthy adults
10,000 ppb (18868 μg/m^3)	N/A	Impairment of ability to detect odour of NO_2
50,000 ppb (94,340 μg/m^3)	N/A	Reversible, nonfatal bronchiolitis
150,000 ppb (283,020 μg/m^3)	N/A	Death after 2 or 3 weeks by bronchiolitis fibrosa obliterans
300,000 (566,040 μg/m^3)	N/A	Rapid death

(adapted from PAS, 2006b)

Nitrogen dioxide contributes to a wide range of environmental effects, including potential changes to the composition and competition of some species of vegetation in wetland and terrestrial systems (USEPA, 2002). NO_2 affects visibility as a result of the formation of a brown color haze. NO_X (NO + NO_2) reacts in the air to form ground-level ozone and fine particulates, which are associated with adverse health effects. Ambient NO_2 also plays an important role in the formation of nitric acid, which is the major component of acid rain, (Legge et al., 1980) and deposits in soil and water, causing acidification of fresh water bodies, eutrophication, and increases in levels of toxins harmful to fish and other aquatic life. Figure 2-1 shows the formation of acid rain and nitrates in the atmosphere in wet and dry conditions. Exposure of vegetation to high concentrations of NO_2 results in silvering of the lower leaf surface, which shortly takes on a waxy appearance (WBEA, 2000). NO_2 can also cause discoloration and harm to fabrics.

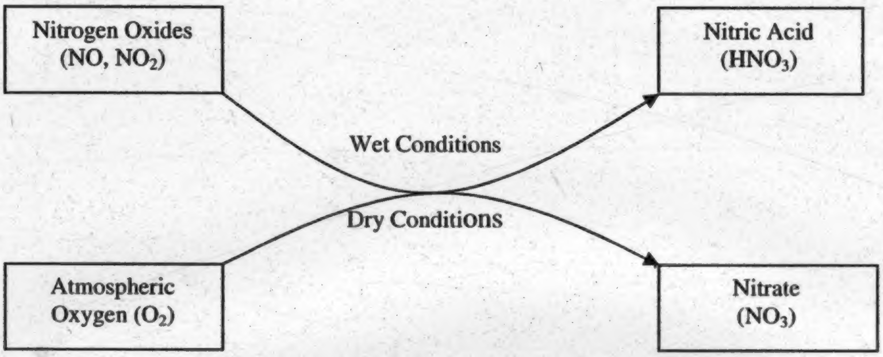
Nitrogen Oxides
(NO, NO_2)
Nitric Acid
(HNO_3)
Wet Conditions
Dry Conditions
Atmospheric
Oxygen (O_2)
Nitrate
(NO_3)

Figure 2-1: Formation of nitric acid (Acid rain) and nitrates from NO_X gases (adapted from Hill, 2004)

2.2.5 Environmental Regulations

Alberta Environment has adopted very rigorous guidelines for nitrogen dioxide levels, with a maximum average concentration of 212 ppb (400 $\mu g/m^3$) as a one-hour average concentration, 106 ppb (200 $\mu g/m^3$) as a 24-hour average concentration, and 32 ppb (60 $\mu g/m^3$) as an annual average concentration (Alberta Environment, 2006b). There are currently no regulations in Alberta for ambient concentrations of NO and NO_X (WBEA, 2003).

Table 2-4: AAAQO, USNAAQS and WHO Ambient Air Guidelines for NO_2

NO_2 Ambient Air Guidelines	**Concentration limits**		
	one-hour	**24-hour**	**Annual Average**
Alberta Ambient Air Quality Objectives (AAAQO)	212 ppb (400 $\mu g/m^3$)	106 ppb (200 $\mu g/m^3$)	32 ppb (60 $\mu g/m^3$)
US National Ambient Air Quality Standards (NAAQS) (Primary Standards)	N/A	N/A	53 ppb (100 $\mu g/m^3$)
WHO Ambient Air Quality Guidelines	110 ppb (207 $\mu g/m^3$)	N/A	21 – 26 ppb (40 – 49 $\mu g/m^3$)

(Source: Alberta Environment, 2006b; USEPA, 2001; WHO, 2006)

2.3 Carbon Monoxide (CO)

2.3.1 Characteristics

Carbon monoxide is a colorless and odorless gas formed by the incomplete combustion of carbon containing material. It is a major component of motor vehicle exhaust. High concentrations of CO generally occur in areas with heavy traffic congestion. Peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are higher and nighttime inversion conditions (when air pollutants are trapped near the ground beneath a layer of warm air) occur more frequently (USEPA, 2002).

2.3.2 Sources

The majority of carbon monoxide found in the air is from anthropogenic sources; only trace quantities are from natural sources (Furmanczyk, 1994). Major sources of CO in urban locations are motor vehicle exhaust emissions, with elevated concentrations occurring during the morning and evening rush hours (USEPA, 2002). According to the USEPA (2002), almost 95% of all CO emissions in major American cities, may come from automobile exhausts. Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources such as wildfires.

2.3.3 Monitoring Methods

CO is monitored continuously by either non dispersive infrared photometry or gas filter correlation (CASA, 2006d). The non-dispersive infrared photometry process is based upon the absorption of infrared light by CO. Gas filter correlation operates on the same principle and is also based on the absorption of energy by CO. However, gas filter correlation is more specific for CO because this method eliminates water vapors, CO_2, and other interferences (CASA, 2006d).

2.3.4 Human Health and Environmental Effects

Carbon monoxide is a toxic gas that can be harmful in small amounts over an extended period of time. Carbon monoxide enters the bloodstream through the lungs and affects the central nervous system by reducing oxygen delivery to the organs and tissues. CO is about 200 times more likely to combine with hemoglobin than is oxygen (Lyons and Scott, 1990). Exposure to CO concentrations in excess of 4000 ppm (4616 mg/m^3) may cause asphyxiation (WBEA, 2000). Long-term exposure to low concentrations may cause adverse effects in people suffering from cardiovascular disease. Table 2-5 shows human symptoms and other health effects resulting from exposure to various CO concentrations.

Table 2-5: Human symptoms and other effects of specific CO concentrations

CO Concentration	**Exposure Time**	**Human symptoms and other effects**
200 ppm (231 mg/m^3)	15 minutes	Mild headache, fatigue, nausea and dizziness
400 ppm (462 mg/m^3)	3 hours	Serious headache - other symptoms intensify and become life threatening after 3 hours
800 ppm (923 mg/m^3)	< 3 hours	Dizziness, nausea and convulsions - unconscious within 2 hours and dead within 2 to 3 hours
3200 ppm (3693 mg/m^3)	< 3 hours	Headache, dizziness and nausea - death within 1 hour

(adapted from PAS, 2006c)

2.3.5 Environmental Regulations

The Alberta Environment guidelines for the maximum permissible concentrations of CO are based on the prevention of adverse human health effects (CASA, 2006d). A comparison of Alberta ambient air quality guidelines with USEPA and WHO standards for ambient CO concentration is presented in Table 2-6.

Table 2-6: AAAQO, USNAAQS and WHO Ambient Air Guidelines for CO

CO Ambient Air Guidelines	Concentration limits	
	one-hour	8-hour
Alberta Ambient Air Quality Objectives (AAAQO)	13 ppm (15 mg/m^3)	5 ppm (6 mg/m^3)
US National Ambient Air Quality Standards (NAAQS) (Primary Standards)	35 ppm (40 mg/m^3)	9 ppm (10 mg/m^3)
WHO Ambient Air Quality Guidelines	25 ppm (29 μg/m^3)	10 ppm (12 μg/m^3)

(Source: Alberta Environment, 2006b; USEPA, 2001; WHO, 2006)

2.4 Fine Particulate Matter ($PM_{2.5}$)

2.4.1 Characteristics

Particulate matter (PM) is a general term used to describe a mixture of solid particles and liquid droplets (except for pure water) which is microscopic in size and found in the air. Such matter includes dust, dirt, soot, and liquid droplets emitted into the air (World bank, 1998). Particulate matter consists of a mixture of larger particles called coarse particles and smaller particles called fine particles. Coarse particles (PM_{10}) are greater than 2.5 μm, but less than or equal to 10 μm in diameter, while the fine particles ($PM_{2.5}$) are less than or equal to 2.5 μm in diameter (Environment Canada/Health Canada, 1999b). Coarse particulate matter contains materials primarily derived from the earth's crust, such as soil and minerals (APEG, 1999). Fine particulate matter is produced by both natural and anthropogenic activities.

2.4.2 Sources

Forest fires are known to be the largest natural source of fine particles (Environment Canada/Health Canada, 1999b). Fine particles of primary anthropogenic or secondary origin include sulfates, nitrates, ammonia, lead, and organic and inorganic carbon compounds. Sulphates are formed from SO_2 emissions from power plants, smelters, and other industrial facilities, while nitrates are formed from NO_x emissions from power plants, incinerators, automobiles, and other types of combustion sources (USEPA, 2004b). Carbon compounds can be emitted directly or can be formed in the atmosphere from organic vapors. The chemical composition of particles depends upon location, time of the year and weather. As compared to coarse particles (PM_{10}), which settle out more rapidly from the air, fine particulates ($PM_{2.5}$) can stay aloft longer. $PM_{2.5}$ can be transported long distances by the wind to areas hundreds of miles away from the place where they were formed (USEPA, 2004b).

2.4.3 Monitoring Methods

The monitoring of $PM_{2.5}$ is done on a continuous as well as intermittent basis. On a continuous basis, $PM_{2.5}$ is monitored by using the Tapered Element Oscillating Microbalance (TEOM) (CASA, 2006e). The TEOM draws an air sample through an inlet stream that aerodynamically separates fine and coarse particles. The air sample then passes through a filter that is attached to a tapered element in the mass transducer. This tapered element vibrates at its natural frequency. As particles are deposited onto the filter, the oscillating frequency changes in proportion to the amount of mass deposited.

On an intermittent basis, $PM_{2.5}$ is monitored using a dichotomous sampler (CASA, 2006e). The dichotomous sampler is a derivative of the high volume sampler. The sampler aerodynamically separates particles into fractions of two sizes: fine and coarse. Fine and coarse particles are collected by drawing a known volume of air through two individual pre-weighed filters for a 24-hour period. The total particulate concentration in the two size ranges may then be calculated for this 24-hour period.

2.4.4 Human Health and Environmental Effects

The most adverse health effect of $PM_{2.5}$ in humans is its effect on the cardio-respiratory (heart-lung) system (World Bank, 1998). The smaller the particle, the deeper it can penetrate into the lungs and the greater is its risk of inducing a negative reaction. The larger particles are caught by cilia which line the walls of the bronchial tubes (lungs) and move the particles up and out of the respiratory tract. The $PM_{2.5}$ penetrates deeper into the lungs into regions where there are no cilia and thus cannot be removed easily. Long-term exposure (several years) to particulate matter causes decreased lung function, development of chronic bronchitis, and premature death (USEPA, 2004b).

Short-term exposure (hours or days) causes decreased lung functions, increased respiratory symptoms, and heart beat irregularities. The severity of the effect of $PM_{2.5}$ on humans is influenced mainly by the chemical composition of the particles, the duration of exposure, and the susceptibility of the individual. Several researchers have found associations between short-term fine particulate matter exposure and increases in mortality and hospital admissions (Samet et al., 2000). Recent studies for evaluating the adverse health effects of fine particulate matter have suggested that higher mortality risks are associated with fine particulate matter ($PM_{2.5}$) rather than with coarse particulate matter (PM_{10}) (Burnett et al., 2000; Pope et al., 2002).

Fine particulates also have adverse ecological effects. One of the significant effects of $PM_{2.5}$ is reduced visibility (Hill, 2004). Visibility impairment occurs when fine particles scatter and absorb light, creating a haze which degrades the color, clarity, and contrast of the view (USEPA, 2004b). Humid conditions in the atmosphere can significantly increase visibility impairment by causing some particles to become more efficient at scattering light. Particulate matter also has adverse effects on materials, causing corrosion and soiling (metals and wood) and failure of vegetation (both agricultural and forest species). The primary mechanisms by which particulate matter affects vegetation includes physical blocking of stomata, physical smothering of leaf surface, and chemical effect due to particle composition (Environment Canada/Health Canada, 1999b). The particulate matter also affects the soil pH and ionic composition.

2.4.5 Environmental Regulations

Guidelines for ambient atmospheric concentrations of $PM_{2.5}$ are under consideration by the Alberta and the Federal governments. A Canada Wide Standard (CWS) benchmark concentration of 30 $\mu g/m^3$ (24-hours) has been adopted for $PM_{2.5}$ in Alberta (CASA, 2006e; WBEA, 2003). The actual achievement statistic for the $PM_{2.5}$ CWS is based on a complex calculation process that involves using the 98th percentile measurement annually, averaged over three consecutive years.

Table 2-7: AAAQO, USNAAQS and WHO Ambient Air Guidelines for $PM_{2.5}$

$PM_{2.5}$ Ambient Air Guidelines	Concentration limits	
	24-hour	Annual Arithmetic Mean
Alberta Ambient Air Quality Objectives (AAAQO) adapted from Canada-wide Standard (CWS)	30 $\mu g/m^3$	N/A
US National Ambient Air Quality Standards (NAAQS) (Primary Standards)	65 $\mu g/m^3$	15 $\mu g/m^3$
WHO Ambient Air Quality Guidelines	N/A	N/A

(Source: Alberta Environment, 2006b; USEPA, 2001; WHO, 2006; CASA, 2006e)

2.5 Total Hydrocarbons (THC)

2.5.1 Characteristics

Total hydrocarbons refer to a range of chemicals that contain carbon and hydrogen atoms. Major forms of total hydrocarbons in ambient air are saturated, unsaturated, and aromatic hydrocarbons. Methane (CH_4), a saturated hydrocarbon, constitutes by far the largest form (by mass) of total hydrocarbons in ambient air (WBEA, 2000). Some other common hydrocarbons include ethane, propane, butane, ethylene, benzene, toluene, and ethylbenzenes.

2.5.2 Sources

Total hydrocarbons are produced both from natural and anthropogenic sources. Major natural sources of THC include fossil fuel deposits, volcanoes, vegetation decay, and bacteria (WBEA, 2000). Trees and plants are the major natural emitters of reactive hydrocarbons. The man-made sources of hydrocarbons include vehicle emissions, gasoline storage tanks, petroleum and chemical industries, dry cleaning, fireplaces, natural gas combustion, and aircraft traffic (CASA, 2006f). The extraction plant vents, tailing ponds, and fugitive emissions from the oil sands industries and/or evaporation of solvents, leaking valves, and compressors at industrial facilities are some other anthropogenic sources of reactive and non reactive hydrocarbons.

2.5.3 Monitoring Methods

Total hydrocarbons are monitored by a hydrogen flame ionization detector (CASA, 2006f). In this method, the hydrocarbons are burned, which breaks the carbon hydrogen bond, creating ions that conduct an electric current. This current is then measured by an electrometer which gives a signal proportional to the number of ions.

2.5.4 Human Health and Environmental Effects

Some specific hydrocarbons can be toxic to humans, animals, and vegetation. Among these are the aromatic hydrocarbon compounds like benzene, toluene, ethylbenzene and xylenes (BTEX), which, when present in sufficient quantities, affect human health (WBEA, 2000). Methane which constitutes a major portion of the non reactive hydrocarbons is a major contributor to the green house effect. Some non-methane hydrocarbons act as precursors to ground level ozone formation and thus present a risk to human health.

2.5.5 Environmental Regulations

Total hydrocarbons are considered to be an indicator of industrial emissions. There are currently no Alberta Ambient Air Quality Guidelines for total hydrocarbons (CASA, 2006f); however, some aromatic hydrocarbons like benzene, toluene, ethylbenzene and xylenes are considered in Alberta Ambient Air Quality Objectives. The Alberta Ambient Air Quality Guidelines for these compounds are given in Table 2-8.

Table 2-8: AAAQO for Benzene, Ethylbenzene, Toluene, and Xylenes

Alberta Ambient Air Quality Objectives (AAAQO)	**Concentration limits**	
	one-hour	**24-hour**
Benzene	9ppb 30 μg/m^3	N/A
Ethylbenzene	460 ppb 2000 μg/m^3	N/A
Toluene	499 ppb 1880 μg/m^3	106 ppb 400 μg/m^3
Xylenes	529 ppb 2300 μg/m^3	161 ppb 700 μg/m^3

2.6 Meteorological Factors Affecting the Dispersion and Persistence of Pollutants in the Atmosphere

The airborne cycle is initiated with the emission of pollutants, followed by their transport and diffusion through the atmosphere (Lyons and Scott, 1990). The transport and dispersion of air pollutants in the atmosphere are influenced by many complex factors. Global and regional weather patterns and local topographical conditions affect how pollutants are transported and dispersed. The primary meteorological factors affecting the concentration of air pollutants are wind, temperature, atmospheric stability, mixing height, precipitation/humidity, and topography.

2.6.1 Wind

One of the primary factors affecting the transport and dispersion of pollutants in the atmosphere is wind. Wind is the natural horizontal motion of the atmosphere; it is caused by differences in pressure and temperature in the atmosphere. Differences in pressure cause air to move from high pressure areas to low pressure areas, resulting in wind (Wark and Warner, 1981). Wind direction indicates the trajectory or path of air pollutants from the source to the receptor. Wind speed determines the distance from the source to the receptor and the time the ambient pollutants will take to reach the receptor (Myrick, 1995). Wind speed near the earth's surface is low due to the frictional effects proportional to the surface roughness; however, wind speed is greater further away from the earth's surface (Wark and Warner, 1981).

Wind speed can greatly affect the pollutant concentrations in a local area. Wind speed determines the extent to which pollutants are initially diluted in ambient air at the point of release. This effect is treated as an inverse relationship between wind speed and concentration of pollutants: the higher the wind speed, the lower the pollutant concentration. Wind dilutes pollutants and rapidly disperses them throughout the immediate area. According to Bronnimann et al. (2002), there is a negative relationship between wind speed and anthropogenic ozone concentration under fair weather conditions and a positive relationship under poor weather conditions for natural ozone. Chaloulakou et al. (2003) studied the relationship between PM_{10} and $PM_{2.5}$ concentration and meteorological variables including wind speed, wind direction, and temperature and found a non-linear relationship.

2.6.2 Temperature

Temperature has an important influence on the existence of various pollutants in the atmosphere (Jandali and Hrebenyk, 1985). The rate of change of temperature with altitude has a substantial effect on the mixing of air pollutants in the atmosphere. The diurnal and seasonal solar cycles essentially control the temperature profile of the lower atmosphere. During the day, the temperature in the lower atmosphere typically increases due to the energy absorbed from the sun. As evening approaches, there is a decrease in solar heating which causes the lower atmosphere to cool. This heat loss from the earth's surface at night results in a temperature inversion which will limit the rise of the plume from pollution sources, resulting in the pollutants staying longer in the atmosphere (Myrick, 1995). Such temperature inversions are common in winter when heat from the sun is minimal. The persistence of temperature inversions over long periods of time may lead to increased concentration of air pollutants in the lower atmosphere from low-level pollution sources. Most chemical reactions in the atmosphere that result in ozone and particulate matter formation proceed faster at higher temperatures (USEPA 2004a; USEPA 2004b). The presence or absence of strong sunlight also affects the availability of oxidizing agents since they are produced by photochemical reactions that require energy from the sun.

2.6.3 Atmospheric Stability

Atmospheric stability is the tendency of the atmosphere to resist vertical mixing or motion (Wark and Warner, 1981). The vertical mixing in the lower atmosphere is primarily dependent upon the temperature gradient and mechanical turbulence. This tendency directly influences the ability of the atmosphere to disperse pollutants emitted into it. A stable atmosphere does not exhibit much vertical mixing or motion, and as a result, pollutants emitted near the earth's surface remain there. When the stability is low, vertical motion is not suppressed, and pollutants are able to disperse higher from the ground surface. Stability is measured by the variation of ambient air temperature with respect to the height above the ground.

2.6.4 Mixing Height

Mixing Height is the thickness of the layer of air in which pollutants are well mixed (Holzworth, 1967). Normally, it is the space between the Earth's surface and the lowest level in the atmosphere at which the ground surface no longer influences the meteorological variables through the turbulent transfer of mass. The greater the vertical extent, the larger the volume of atmosphere available to dilute the pollutant concentrations. Thermal buoyancy effects determine the depth of the convective mixing layer, which is taken as the maximum mixing depth (MMD) (Wark and Warner, 1981).

In unstable air, the MMD is higher, and in stable air, the MMD is lower. There is also a seasonal variation in mixing depth. During summer daylight hours, the MMD can be a few thousand feet, whereas in winter, it can be a few hundred feet. Mixing depth also varies over the course of a day, being lowest at night and higher during the day. A measure of both MMD and wind speed with respect to height can give a good idea of the amount of pollutant dispersion in the atmosphere.

2.6.5 Precipitation/Humidity

In meteorology, precipitation is any kind of water that falls from the sky as part of the weather, including snow, rain, sleet, freezing rain, and hail, whereas humidity is the amount of moisture in the air. Precipitation and humidity sometimes have a beneficial effect on the environment by washing pollutant particles from the air; however, precipitation can also act on pollutants in the air to create more dangerous secondary pollutants, such as the substances responsible for acid rain (Elsom, 1992). Small water droplets in clouds or fog can increase particle formation rates. For example, sulphur dioxide is converted to sulphate much more quickly under foggy conditions, leaving higher particle concentrations in the air after the fog has evaporated. Kim et al. (1997) found a strong inverse relationship between relative humidity and lead (Pb) levels in the air; however, a weak positive and negative correlation was found for the particulate matter in the air.

2.6.6 Topography

Land orientation and the structure of terrain also influence and even control air motion and mechanical turbulence in the lower atmosphere. Terrain factors such as mountains, hills, and valleys have a significant effect on pollutant dispersion as they largely control wind speed and wind direction (Myrick, 1995). Large mountains and hills may divert the wind and channeled it through valleys. Highly variable terrain features of an area may also affect the diurnal variations of wind.

2.7 Air Quality Trends

There are two basic types of trends that can be statistically analyzed: step trends and monotonic trends (Oregon DEQ, 2003). Step trends include either a sudden increase or decrease in concentration resulting from sudden change. Monotonic trends are generally gradual changes that are either increasing or decreasing with no reversal of direction. The main purpose of air quality trends analysis is to link observed changes in air quality to trends in emissions, with a view of assessing the success of various emission-control strategies.

According to Blanchard (1999), the usefulness of trend analysis depends on the magnitude of emissions of interest, quality, and length of record of monitoring data, and relative magnitudes of emissions-and-weather driven variations in ambient concentrations. Other studies have reported that estimation of emission-related trends require statistical models that account for sources of variability underlying the pollutants, such as seasonal changes and meteorology (Porter et al., 2001; Lynch et al., 2000; Holland et al., 1999).

Weatherhead et al. (1998) discussed statistical criteria for detecting linear trends in environmental data and reported that precision of trend estimates is strongly influenced by variability and autocorrelation of the underlying noise process. According to

Weatherhead et al. (1998), detectability of a trend can be summarized in two common ways:

a) through precision of a trend estimate as measured by its standard deviation, and

b) number of years of data required to detect a trend of a given magnitude using the trend estimate.

Weatherhead et al. (1998) concluded that it takes several decades of high-quality data to detect trends likely to occur in nature. The practical implication is that detection of trends over shorter time periods (less than a decade) does not represent long-term trends. Responding to public perceptions and concerns about air quality remains a challenge and requires sound assessment. It is of great interest to know whether changes in air quality have occurred over time where continuous air monitoring is conducted. Assessment of short-term trends offers a credible scientific approach for responding to public perceptions and concerns about air quality and establishing whether or not change may be occurring.

Several methods are used in environmental statistics for the measurement of trends. Three widely used methods for detecting trends in air quality are the Linear Regression, the Seasonal Mann Kendall test, and the t – test adjusted with seasonality.

2.7.1 Linear Regression

Regression analysis is a popular statistical tool for illustrating trends. Linear regression attempts to model the relationship between two variables by fitting a linear equation to the observed data (Freund and Wilson, 2003). One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. Linear regression is useful for exploring the relationship of an independent variable that marks the passage of time with a dependent variable when the relationship is linear, i.e., when there is an obvious downward or upward trend in the data over time (Gilbert, 1987).

Linear regression, however, fails to capture seasonal, cyclical, and counter-cyclical trends in time series data. Neither does it capture the effects of changes in the direction of time series data, nor changes in the rate of change over time. For time series regression, it is important to obtain a plot of the data over time and inspect it for possible non-linear trends. There is also a problem of auto-correlation in the time series data, if the values at one point in the time series are determined or strongly influenced by values at a previous time. Auto-correlation occurs when the values of the dependent variable over time are not randomly distributed. This problem can more likely be satisfied by using the yearly average as response variable (Hess et al., 2001).

2.7.2 Seasonal Mann Kendall test

The Seasonal Mann Kendall test is an extension of the Mann Kendall test that accounts the seasonality in the data (Hess et al., 2001). It is a distribution-free, nonparametric test that compares relative ranks of data values from the same season. For example, January (seasonal) values are compared to January (seasonal) values; February (seasonal) values are compared to February (seasonal) values, and so forth. No comparisons are made across seasonal boundaries. The test assumes that the data are independent and from the same statistical distribution.

The Seasonal Mann Kendall test statistic is the summation of the Mann-Kendall test results from all the seasons. A Mann-Kendall test statistic (S) and variance (VAR) are calculated separately for each season with the data collected over the year. These seasonal statistics are then summed and a Z statistics is calculated (Gilbert, 1987). The trend test statistic (Z) is used as a measure of trend magnitude or of its significance. The null hypothesis can be accepted or rejected for the presence of trend by comparing the Z statistics with the Z_α or $Z_{\alpha/2}$, where α is the chosen significance level. The Seasonal Kendall slope estimator is computed as the median slope of all the pair-wise comparisons from all of the seasons expressed as rate of change per year (Gilbert, 1987).

The Seasonal Mann Kendall test is a rank-based procedure and is suitable for non-normally distributed data. It can also capture outliers and non-linear trends, which can cause a disproportionate influence on the estimate of slope calculated by linear regression. One of the limitations of the Seasonal Mann Kendall test is that it is restricted to monotonic trends, which provides a limited insight in comparison to other statistical methods (Gilbert, 1987).

2.7.3 t – test Adjusted with Seasonality

One of the simplest approaches to detect a trend is by assessing a statistically significant difference between the theoretical means (μ) using a two-sample t-test. The t-test helps to determine if the true slope is not different from zero (Snedecor and Cochran, 1980). Unfortunately, the t-test can be misleading if there are seasonal cycles in the data, the data are not normally distributed, or the data are serially correlated (Gilbert, 1987). Hirsch et al. (1982) found that in these situations, the t-test may indicate a significant slope when the true slope is zero.

The seasonal effect can be incorporated into a t-test by using a linear model that includes the seasons and the year as factors, with the assumption that both season and year effects are considered fixed. According to Hess et al. (2001), if Y_{ijk} be the (k^{th}) observation from season (j) of year (i), with the assumption that these values are independent with constant variance, then the following model can be obtained:

$$Y_{ijk} = \mu + T_i - M_j - e_{ijk} \qquad [6]$$

Where (T_i) is the effect for the year (i), (M_j) is the effect for season (j), and (e_{ijk}) is the error which is independently and identically normally distributed with mean 0 and variance σ^2_e.

CHAPTER 3: METHODOLOGY

3.1 Monitoring Data

Air quality is monitored continuously at the Edmonton Northwest and Fort McKay stations. Data from these stations (as hourly average concentrations) were obtained from the Clean Air Strategic Alliance (CASA) Data Warehouse website (http://www.casadata.org). Data used in this study for CO, NO_2 and O_3 from the Edmonton Northwest station were from the last eight years (1997 to 2004). $PM_{2.5}$ data for the Edmonton Northwest station were obtained for the last six years (1999 to 2004) because the first 3½ months of values for the 1998 dataset were missing such that it could not be considered valid for trend analysis. NO_2, O_3, $PM_{2.5}$, and THC data from the Fort McKay station were available only for six years (1999 to 2004). The instruments used for measuring concentration of various pollutants at Edmonton Northwest and Fort McKay stations (with their respective detection limits) are given in Table 3-1.

Table 3-1: Types of instruments for measuring various pollutants and their respective detection limits (Benders, 2006)

Pollutants	**Instrument type**	**Detection limit**
$PM_{2.5}$	R & P TEOM 1400 AB	0.1 µg/m^3
CO	Thermo Environmental Model 48C	0.1 ppm
O_3	Thermo Environmental Model 49C	1 ppb
NO_2	Thermo Environmental Model 42	1 ppb
THC	Bendex 8201	0.1 ppm

3.2 Simple Statistical Analysis

All hourly average concentration values were preprocessed to remove missing and erroneous data. A minimum standard of 90% data-completeness was used to determine whether to carry an annual dataset forward for trend analysis. The percent of non-detects (values less than the detection limit), maximum, minimum, and median values were recorded for each dataset. These results are presented in Appendix 7.1 and 7.2.

Diurnal, weekly, and seasonal (monthly) patterns were examined using the entire data set for each pollutant. For example, for diurnal patterns, the average ozone concentration for the Edmonton Northwest station at 8:00 was calculated as the average of all 8:00 hour readings in the data period (1997 to 2004), regardless of the day of the week or season. Yearly averages and number of hours in which average hourly concentrations exceeded the maximum one-hour concentration AAAQO were also counted for each pollutant.

3.3 Temporal Trend Analysis Using Regression

Yearly data sets from the CASA Data Warehouse were obtained in a time-series format. These datasets were transformed into an ascending concentration-based order which were ranked (cumulative rank) and assigned a percentile frequency. A plot of concentration values versus percentile frequency was used to show the cumulative frequency distribution of a respective pollutant for a year. Cumulative frequency distribution plots for selected pollutants are presented in Appendices 7.3 through 7.10. This procedure was used to select and examine changes (trends) in various hourly concentrations at different percentiles of a distribution.

Using an assumption that ambient air concentrations display a temporal trend with time, two simple benchmark methods were used for detection of air quality trends:

- a concentration-based benchmark (based on concentrations of various pollutants between the 50th and 98th percentiles for each year), and
- a frequency-based benchmark (based on various percentiles between the 50th and 98th percentiles representing frequencies or number of hours for which the concentration of various pollutants were exceeded each year).

A concentration-based benchmark was the concentration of the pollutant corresponding to a respective percentile on a cumulative frequency distribution plot. A frequency-based benchmark was determined by selecting a concentration corresponding to a percentile on the cumulative frequency distribution plot for a starting year (e.g. 50th percentile for CO in 1997) and then counting the number of hours exceeding that concentration in subsequent years.

A parametric approach was applied to analyze trends in concentrations (concentration-based approach) and exceedence frequency hours (frequency-based approach). These summary statistics were assumed to be linear in time and were analyzed using simple linear regression. Simple linear regression is a powerful tool used to find the best fit line by minimizing the sum of squared errors (Harnett, 1982). Hypothesis testing using Student t-test and the ANOVA was conducted to examine whether the slope of the best fit line was greater or less than zero at a significance level of $\alpha = 0.05$. Section 3.3.1 explains the regression procedure used for trend analysis.

3.3.1 Regression Analysis

Microsoft Excel was used for the regression analysis. The following assumptions were made while using the regression technique:

- the concentration/frequency variable was assumed to be normally distributed, and
- the summary statistics were assumed to be linear in time to enable regression analysis.

Data in the form of concentrations (concentration-based approach) and hourly frequencies (frequency-based approach) for various years were plotted. Such plots help to visually determine whether a straight line approximation to the data appears reasonable, and to make rough estimates of the intercept (a) and slope (b). A model with a least square regression line was obtained for every plot of the various percentiles using the "add trend line" function in Excel. The regression model used the following equation:

$$\hat{y} = bx_i + a \qquad [7]$$

Where b is the slope,

a is the intercept,

x_i is the concentration/frequency, and

$\hat{y}$ is the estimated y.

The b and a can also be calculated mathematically by the following formula (Harnett, 1982):

$$b = \frac{\frac{1}{n-1}\sum_{i=1}^{n}\left(y_i - \overline{y}\right)\left(x_i - \overline{x}\right)}{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \qquad [8]$$

and $a = \bar{y} - b\bar{x}$ [9]

The slope, b, for each best fit line determined using regression analysis was tested with a t-test and ANOVA at a significance level of $\alpha = 0.05$ to establish whether it was different from 0.

3.3.2 t - test

The hypothesis made for the t-test were

H_0: Slope $= 0$, and

H_1: Slope $\neq 0$.

The formulas used for the t- test consisted of (Harnett, 1982)

$$t_{(statistics)} = \frac{\text{Statistic hypothesized value}}{\text{Estimated standard error of the statistic}} \qquad [10]$$

or

$$t_{(n-2)} = \frac{b - b_0}{S_b} \qquad [11]$$

where $b_0 = 0$ and b = slope and

$$S_b = \frac{S_e}{\sqrt{SSX}} \qquad [12]$$

where SSX is the Standard Error of the Estimates

$$SSX = \sum (X - \bar{X})^2, \qquad [13]$$

$$S_e = \sqrt{\frac{SSE}{(n-2)}} \qquad [14]$$

where SSE is the Sum of Squared Error

$$SSE = \sum (Y - \hat{Y})^2 \qquad [15]$$

such that if $t_{\text{(calculated)}} > t_{\text{(tabulated)}}$,

then reject H_0 and the slope $\neq 0$.

This type of outcome represents a trend (increasing if a positive slope and decreasing if a negative slope).

3.3.3 ANOVA (F - test)

The hypothesis made for the ANOVA test were

H_0: Slope = 0 and

H_1: Slope $\neq 0$.

Formulas used for the ANOVA (F-test) consisted of (Harnett, 1982)

$$F_{\text{(Statistics)}} = F_{(1,\,n-2)} = \frac{MSR}{MSE} \qquad [16]$$

$$MSE_{\text{(Mean Square Error)}} = \frac{SSE}{(n-2)} \qquad [17]$$

$$MSR_{\text{(Mean Square Regression)}} = \frac{SSR}{1} \qquad [18]$$

such that if $F_{\text{(calculated)}} > F_{\text{(tabulated)}}$

then reject H_0 and the slope $\neq 0$.

This type of outcome represents a trend (increasing if positive slope and decreasing if negative slope).

Results of regression analysis, t-tests and F-tests were further confirmed using the "Data Analysis – Regression" function of the program Excel in Microsoft Office®. A sample calculation of regression analysis with hypothesis testing using the t-test and F-test at a significance level of $\alpha = 0.05$ is given in Appendix 7.11.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Diurnal, Day of the Week, and Monthly Patterns for Pollutants in Edmonton

Annual means, diurnal hourly averages, day of the week, and monthly patterns were analyzed for the selected pollutants.

4.1.1 Ozone

Yearly average and one-hour maximum O_3 concentrations were identified. It was observed that hourly O_3 concentrations exceeded the Alberta Ambient Air Quality Objectives (AAAQO) of 82 ppb (160 $\mu g/m^3$) several times in 1998, 2002, and 2003 (Figure 4-1). The highest measured O_3 concentration of 94 ppb (184 $\mu g/m^3$) was recorded in 2002. Mean yearly average O_3 concentrations ranged from 17 ppb (33 $\mu g/m^3$) to 21 ppb (41 $\mu g/m^3$).

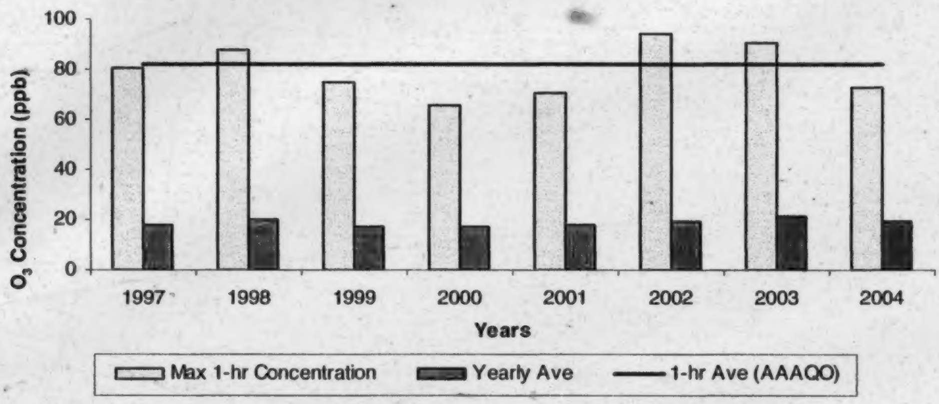

Figure 4-1: Yearly average and one-hour maximum concentrations of O_3 (1997-2004) at the Edmonton Northwest air monitoring station

Diurnal hourly average patterns for ozone showed a definite relationship between O_3 concentration and hour of the day, reflecting the importance of photochemical reactions during the daytime. Primary O_3 peaks were recorded during the afternoon from 12:00 to 16:00 hours (Figure 4-2). Minimum O_3 concentrations were observed late at night and early in the morning. The diurnal peak showed that O_3 concentrations tended to increase to a maximum in the late afternoon and then drop off to a minimum late at night. The afternoon peak in ozone concentration is also due to a corresponding peak in atmospheric instability (Myrick, 1995), which increases vertical mixing of the air in the troposphere during the day which increases the ozone concentration.

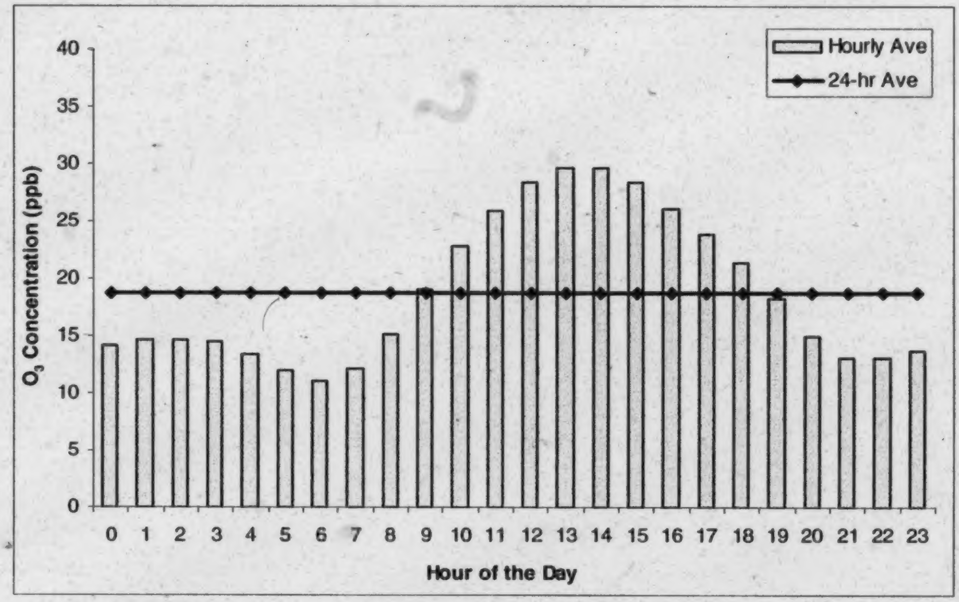

Figure 4-2: Diurnal hourly average concentration trends of O_3 (1997-2004) at the Edmonton Northwest air monitoring station

The day of the week patterns for ozone at the Edmonton Northwest station did not show any changes in the concentration during the week, as can be seen in Figure 4-3.

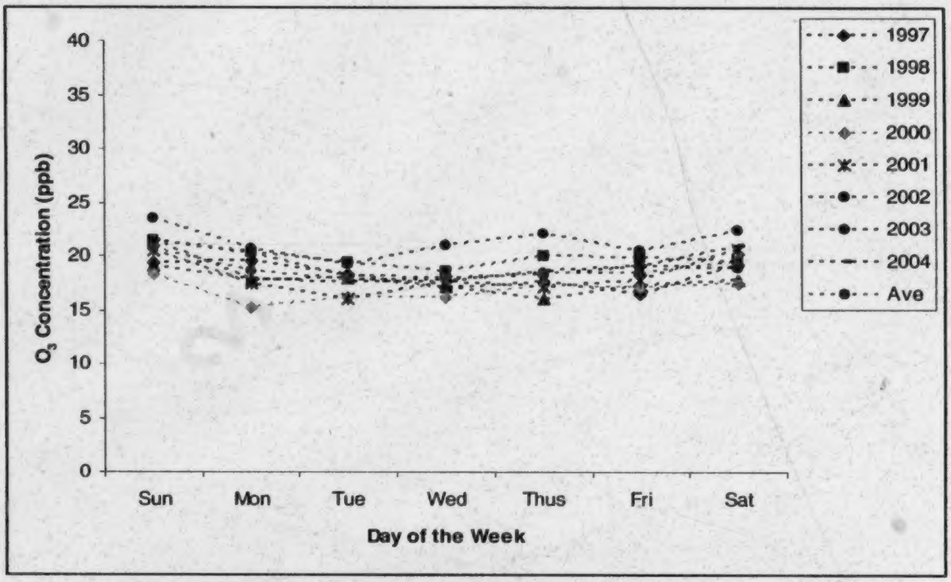

Figure 4-3: Day of the week trends of hourly average O_3 concentrations (1997-2004) at the Edmonton Northwest air monitoring station

The monthly patterns of average hourly ozone concentration show a peak in the months of April to August (Figure 4-4). The peak showed a steady decrease as the summer progressed. This pattern suggests that natural incursions of ozone-rich air from the stratosphere occurred, as the troposphere is at its lowest level during spring in western Canada (Environment Canada/Health Canada, 1999a) and the vertical air currents allow air from the upper elevations to reach the ground. This situation is further aggravated when ultraviolet light is absorbed by the earth's surface in the hot summer season, increasing the photochemical reaction for ozone formation. In summer, the hours of sunlight are longer which may cause reactive pollutants to remain in a region for a prolonged period of time (Myrick, 1995). All the exceedences of the one-hour AAAQO standard at the Edmonton Northwest station occurred in the months of July, August, and September which supports the theory elevated ozone concentration values during summer due to higher photochemical reactions.

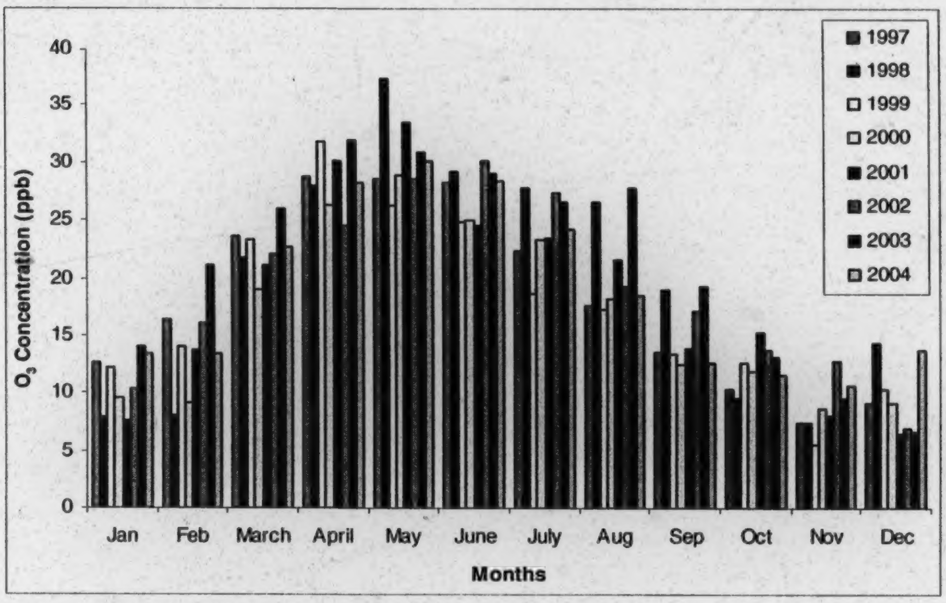

Figure 4-4: Monthly patterns of hourly average concentration values of O_3 at the Edmonton Northwest air monitoring station

4.1.2 Nitrogen Dioxide (NO_2)

No exceedences of the one-hour AAAQO of 212 ppb (400 μg/m^3) were observed for NO_2 from 1997 to 2004 (Figure 4-5). The highest one-hour concentration was recorded at 170 ppb (321 μg/m^3) in 1997 which was below the AAAQO. The highest yearly average of 7 ppb (13 μg/m^3) was recorded in the same year.

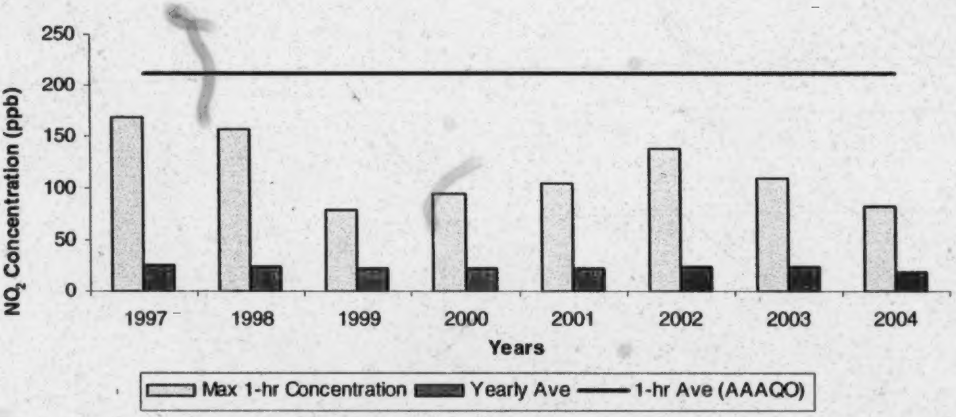

Figure 4-5: Yearly average and one-hour maximum concentrations of NO_2 (1997-2004) at the Edmonton Northwest air monitoring station

Two clear peaks were observed for NO_2, one during the morning from 6:00 to 8:00 and another in the evening from 20:00 to 22:00 (Figure 4-6). NO_2 values tended to be at a minimum in the mid-day at 13:00. The increase in the NO_2 concentrations during the morning and evening hours may be due to the higher volumes of traffic and other anthropogenic actives. The NO emitted from these sources is quickly converted to NO_2. During mid-day, sunlight and comparatively warmer temperatures favor the formation of ozone, thus some of the NO_X emitted from these sources are utilized in the formation of ozone which decreases the NO_2 concentration during the mid-day. The NO_2 concentration begins to rise again in the evening when ozone formation starts to decrease and most of the NO is converted to NO_2. These diurnal hourly peaks are prevalent during winter months when the concentration of NO_2 is relatively higher (Myrick, 1995).

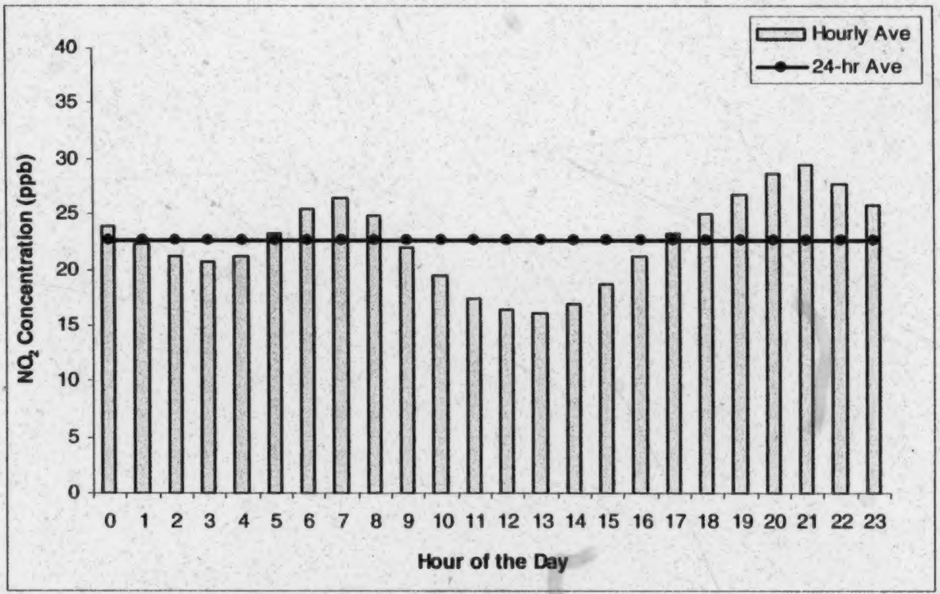

Figure 4-6: Diurnal hourly average concentration trends of NO$_2$ (1997-2004) at Edmonton Northwest air monitoring station

The day of the week patterns for NO$_2$ data showed slightly higher concentrations of NO$_2$ on weekdays than on weekends (Figure 4-7). According to the Environment Canada 1985 emissions inventory for nitrogen oxides, one of the major sources of NO$_X$ gases in Alberta is transportation (44%) (Kosteltz and Deslauriers, 1990). This claim strongly supports the day of the week analysis for NO$_2$ concentrations because the use of transportation is lesser during weekends than on weekdays.

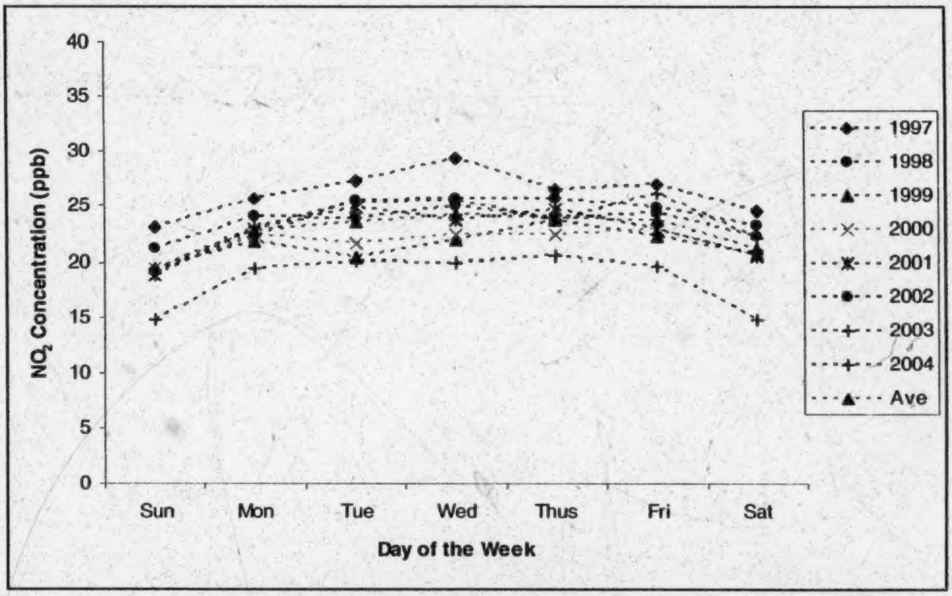

Figure 4-7: Day of the week patterns of hourly average NO_2 concentrations (1997-2004) at the Edmonton Northwest air monitoring station

The monthly patterns for NO_2 show higher concentrations of NO_2 in the months of December, January, and February (Figure 4-8). The minimum NO_2 concentration was observed in July. In winter, heating fuel consumption and automobile emissions tend to be highest which increases the NO_2 concentration dramatically. Persistent temperature inversions in winter also retard the dispersion of pollutants, thus leading to higher pollutant concentrations. According to Legge et al. (1980), during the winter months, the concentrations of NO_X monitored in Edmonton by Alberta Environment are among the highest in Canada and can be attributed to high traffic density and stable meteorological conditions during winter. The lower NO_2 concentrations in the summer may result from instability in the lower troposphere which allows pollutants to disperse. Also, in summer, the ozone concentration is much higher, possibly causing the NO_X (in urban areas) to be utilized as ozone precursors/ozone scavengers, thus lowering the NO_2 concentrations.

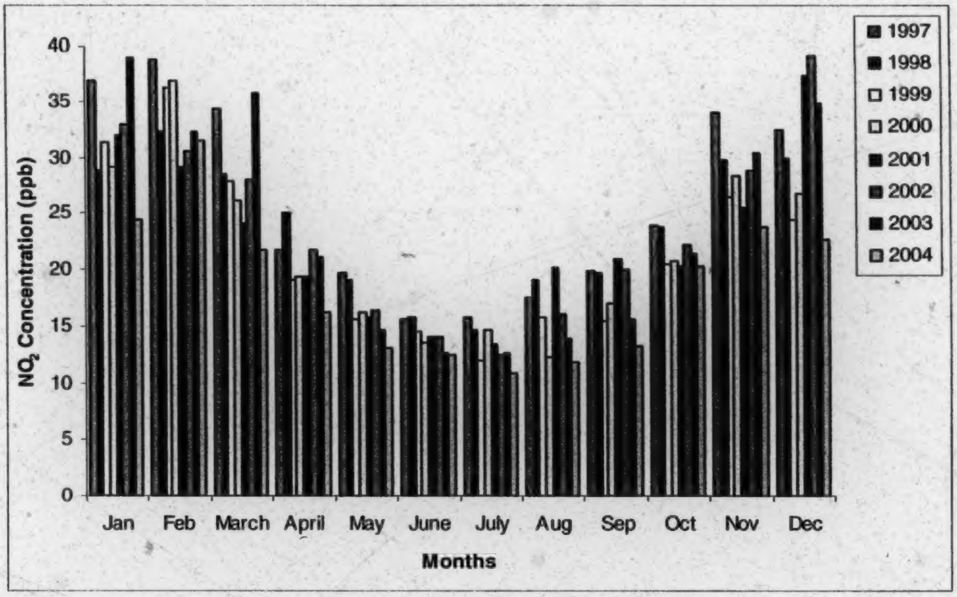

Figure 4-8: Monthly patterns of hourly average concentration values of NO_2 at the Edmonton Northwest air monitoring station

4.1.3 Carbon Monoxide (CO)

One-hour maximum concentrations for CO were observed and it was found that there were no exceedences of the one-hour AAAQO of 13 ppm (15 mg/m^3) from 1997 to 2004 (Figure 4-9). The highest one-hour concentration recorded was 11 ppm (13 mg/m^3) in 2001. Yearly average concentrations were observed to be between 0.5 ppm (0.6 mg/m^3) and 0.7 ppm (0.8 mg/m^3).

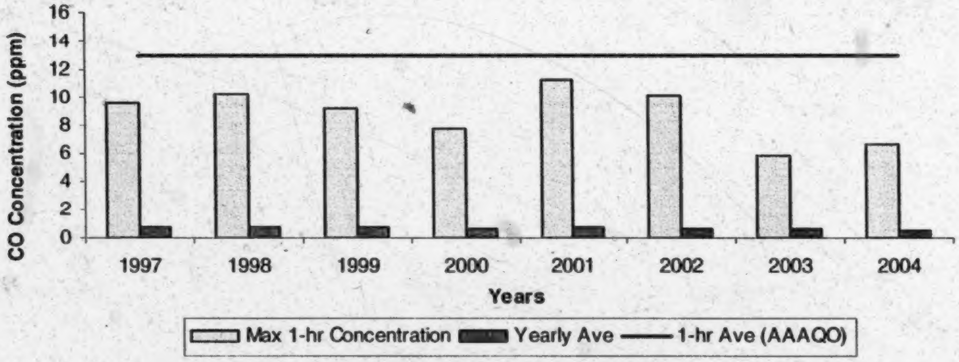

Figure 4-9: Yearly average and one-hour maximum concentrations of CO (1997-2004) at the Edmonton Northwest air monitoring station

Diurnal CO patterns indicated peaks occurring twice a day, once in the morning (6:00 – 8:00) and once in the evening (18:00 – 22:00). Figure 4-10 shows that these peaks occur during or immediately after rush hour traffic. According to Kosteltz and Deslauriers (1990), 85% of CO in urban areas of Alberta is emitted by transport vehicles. The Edmonton Northwest station was located on 127 Street, which has heavy traffic density during morning and evening rush hours (City of Edmonton, 2005a), and this might cause the morning and evening CO peaks. Su et al. (2004) observed similar CO diurnal hourly average trends for the Edmonton East station. It was observed that the evening peak persists longer, with a decrease late at night. The lowest CO values were observed overnight when vehicle traffic is at a minimum.

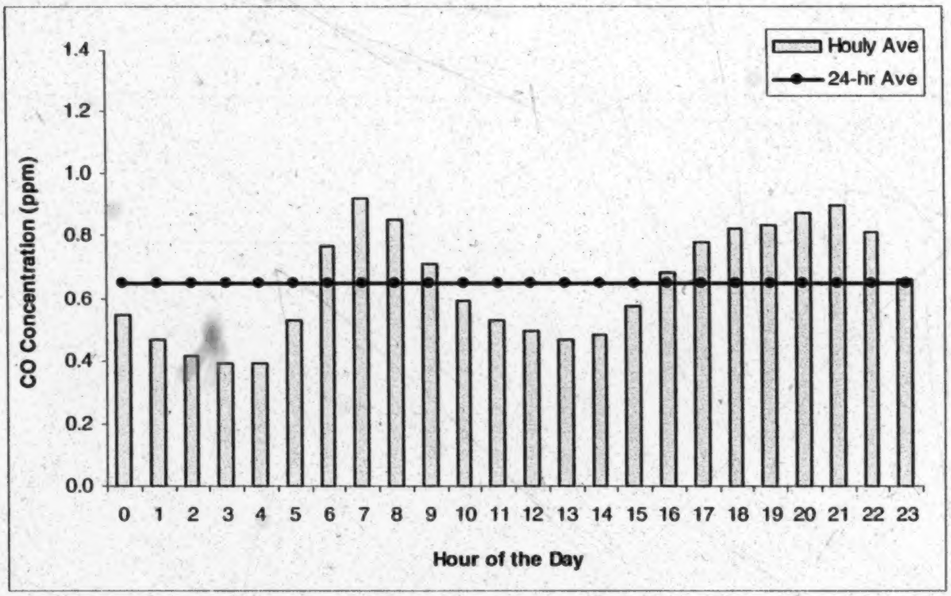

Figure 4-10: Diurnal hourly average concentration trends of CO (1997-2004) at Edmonton Northwest air monitoring station

Figure 4-11 shows the day of the week patterns for CO concentration at Edmonton Northwest station. The CO concentration was found to be slightly higher on weekdays than on weekends. As the biggest portion of CO emissions in urban areas is from automobiles (USEPA, 2001), lower concentrations of CO on weekends are due to the less frequent use of automobiles.

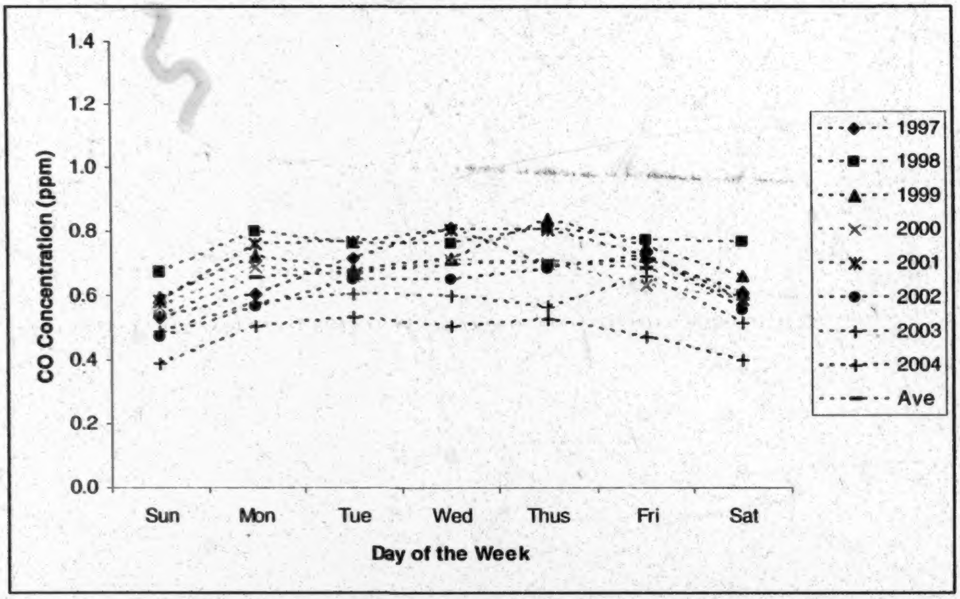

Figure 4-11: Day of the week trends of hourly average CO concentrations (1997-2004) at the Edmonton Northwest air monitoring station

Figure 4-12 shows a clear seasonal fluctuation in CO concentrations, with the highest values in the winter (November – February). The minimum CO concentration was observed in June/July. These higher concentrations of CO in the winter may be the result of meteorological conditions, such as stable atmospheric conditions and low wind speeds, both of which result in decreased pollutant dispersion (Myrick, 1995). These temperature inversions during winter are more likely to persist throughout the day due to a lack of solar heating. Persistent inversions, coupled with longer vehicular idling and warm up times, lead to increased CO concentrations during winter months. In winter, due to cold weather, motor vehicles run less efficiently and use more gasoline, which also increases CO emissions.

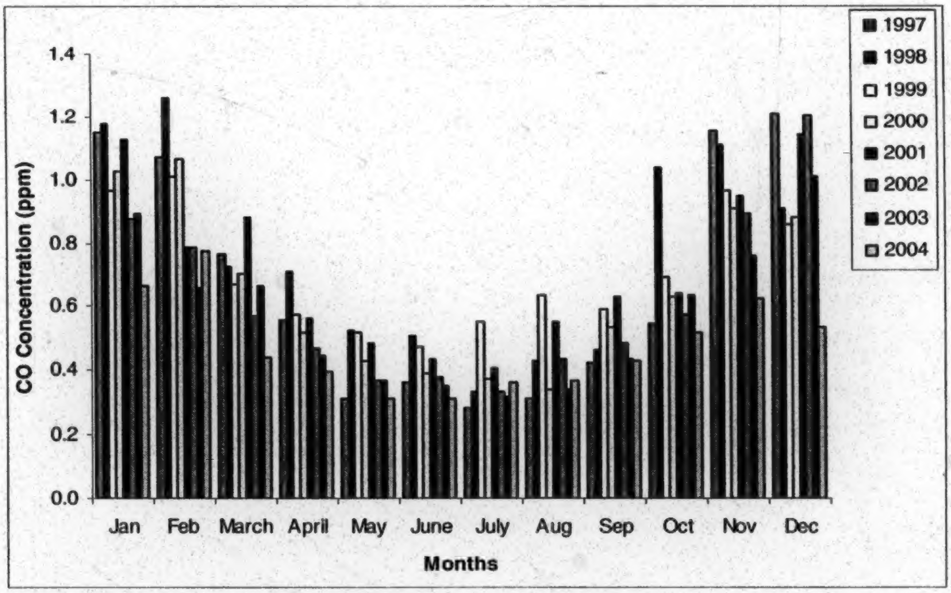

Figure 4-12: Monthly patterns of hourly average concentration values of CO at the Edmonton Northwest air monitoring station

4.1.4 Fine Particulate Matter ($PM_{2.5}$)

In urban areas, anthropogenic influences such as transportation related emissions and industrial activities are believed to be the major sources of ambient $PM_{2.5}$ (USEPA, 2004). Hourly average $PM_{2.5}$ concentrations were examined for the period 1999 to 2004. One-hour maximum concentrations recorded during these years ranged from 97 to 300 $\mu g/m^3$ (Figure 4-13). The annual average concentration recorded for various years ranged from 6 to 12 $\mu g/m^3$.

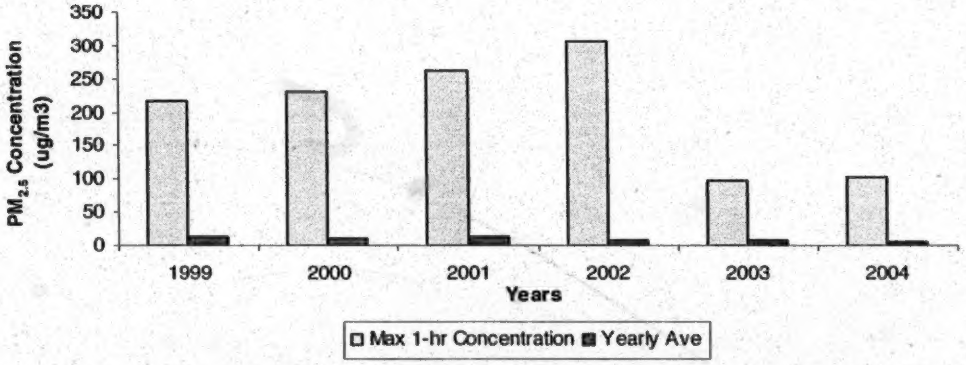

Figure 4-13: Yearly average and one-hour maximum concentrations of $PM_{2.5}$ (1999-2004) at the Edmonton Northwest air monitoring station

Average daily distributions for $PM_{2.5}$ concentrations exhibited two small peaks, one during mornings from 7:00 to 9:00 and the other during evenings from 19:00 to 22:00 (Figure 4-14). These peaks may represent the morning and evening rush hours. Figure 4-14 shows that the evening peak persists longer than the morning peak. The lowest concentration for $PM_{2.5}$ was observed during the early morning hours.

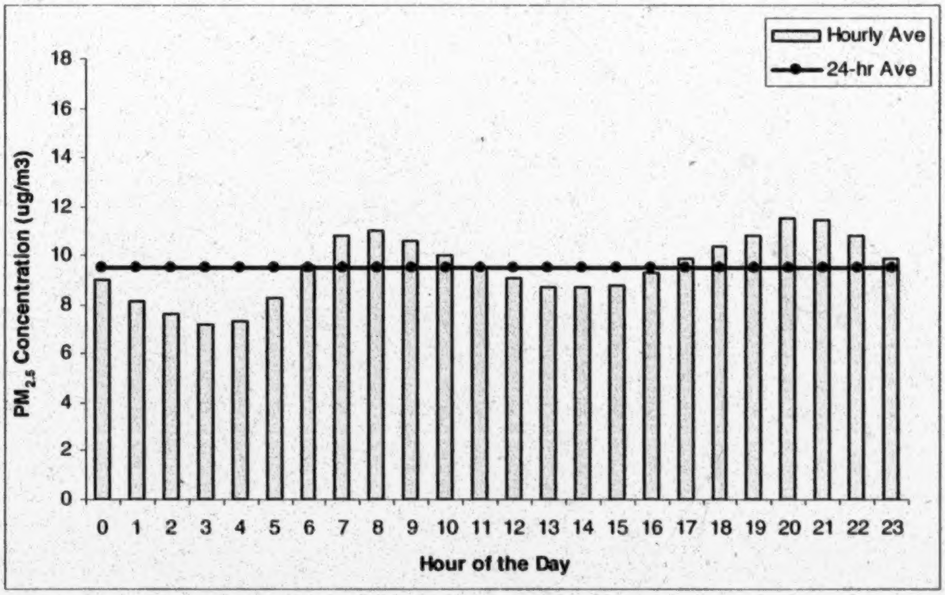

Figure 4-14: Diurnal hourly average concentration trends of $PM_{2.5}$ (1999-2004) at Edmonton Northwest air monitoring station

The day of the week patterns for $PM_{2.5}$ are shown in Figure 4-15. Slightly higher $PM_{2.5}$ concentrations were observed on weekdays than on weekends. This result reflects the effect of anthropogenic emissions (mainly emissions from motor vehicles) on ambient $PM_{2.5}$ concentrations recorded during weekdays. A weekend peak of $PM_{2.5}$ concentrations was observed to be more moderate and was likely due to fewer motor vehicles on the roadways as compared to weekdays. McCullum et al. (2003) also found higher concentrations of $PM_{2.5}$ and PM_{10} on weekdays compared to weekends in downtown Edmonton and Calgary.

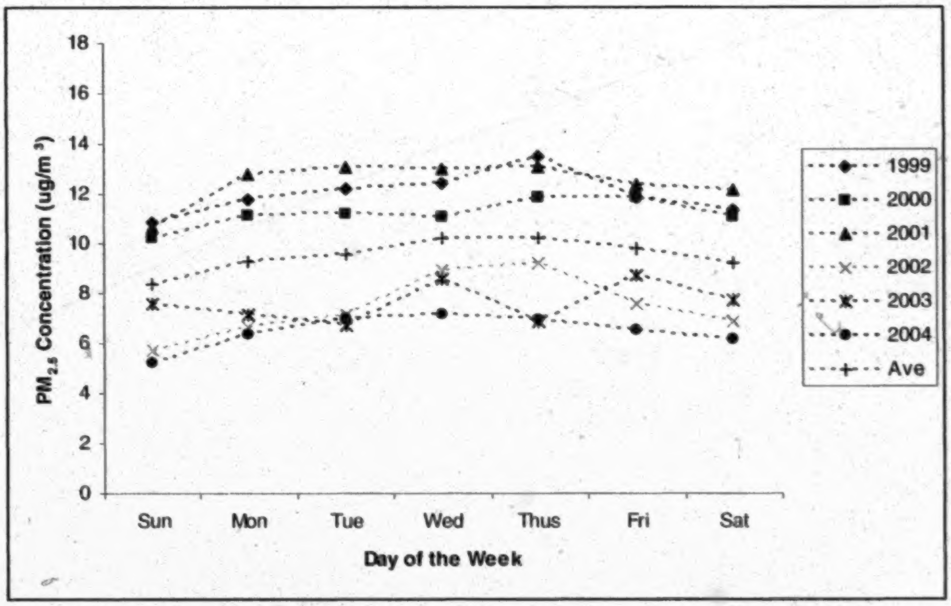

Figure 4-15: Day of the week trends of hourly average $PM_{2.5}$ concentrations (1999-2004) at the Edmonton Northwest air monitoring station

Unlike monthly/seasonal variations for other pollutants in Edmonton, no observable seasonal trends for $PM_{2.5}$ were apparent in this data set (1999-2004), as can be seen in Figure 4-16.

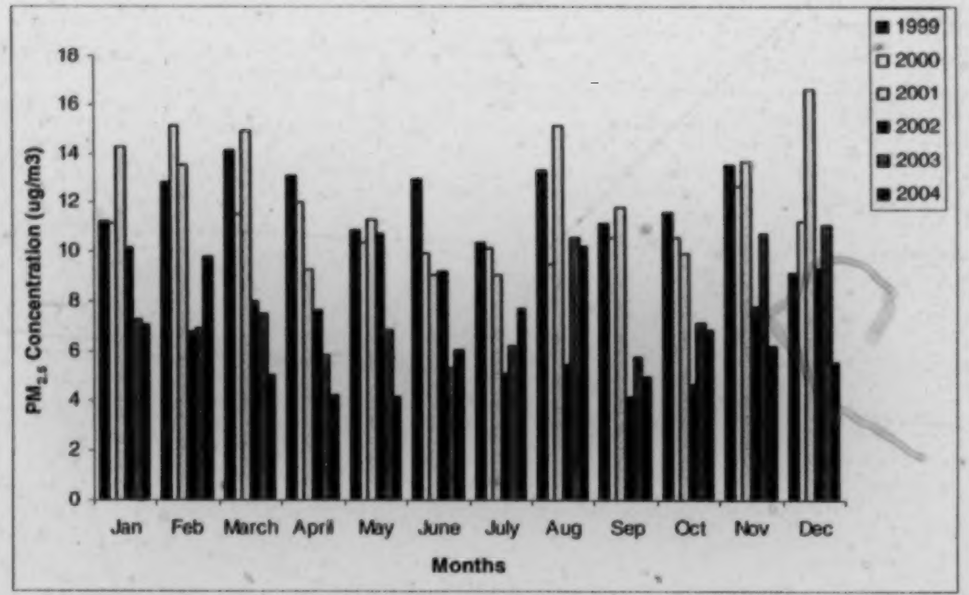

Figure 4-16: Monthly patterns of hourly average concentration values of PM$_{2.5}$ at the Edmonton Northwest air monitoring station

4.2 Diurnal, Day of the Week and Monthly Patterns for Pollutants in Fort McKay

Annual means, diurnal hourly average, day of the week, and monthly patterns were analyzed for the selected pollutants.

4.2.1 Ozone (O_3)

As can be seen in Figure 4-17, one-hour maximum O_3 concentrations recorded at Fort McKay exceeded the AAAQO of 82 ppb (160 μg/m^3) only once during six years. O_3 concentrations in rural areas of Alberta are generally higher than in urban areas (Myrick and Hunt, 1996). Yearly average concentrations recorded from 1999 to 2004 in Fort McKay ranged from 20 ppb (39 μg/m^3) to 23 ppb (45 μg/m^3) which were higher than the yearly averages observed at the Edmonton Northwest air monitoring station.

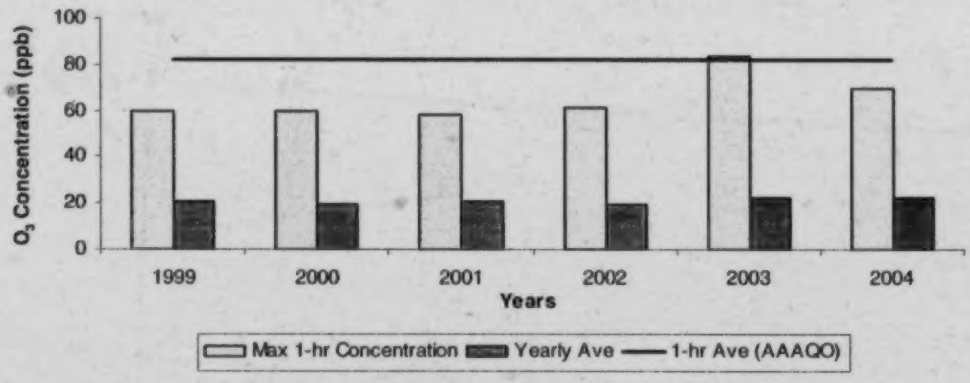

Figure 4-17: Yearly average and one-hour maximum O_3 concentrations at Fort McKay air monitoring station

Diurnal hourly average concentration trends for ozone in Fort McKay showed a small peak during the afternoon (Figure 4-18), which shows higher ozone concentration due to photochemical reactions during mid-day. This peak was not found to be as sharp as that found at the Edmonton Northwest station. As a rural/industrial area, Fort McKay showed relatively higher concentrations of ozone during the day as compared with

Edmonton. According to Elsom (1992), in rural areas, there is insufficient NO_X (which may act as ozone sink) for the ozone to react with, thereby allowing the ozone concentration to remain higher in these areas.

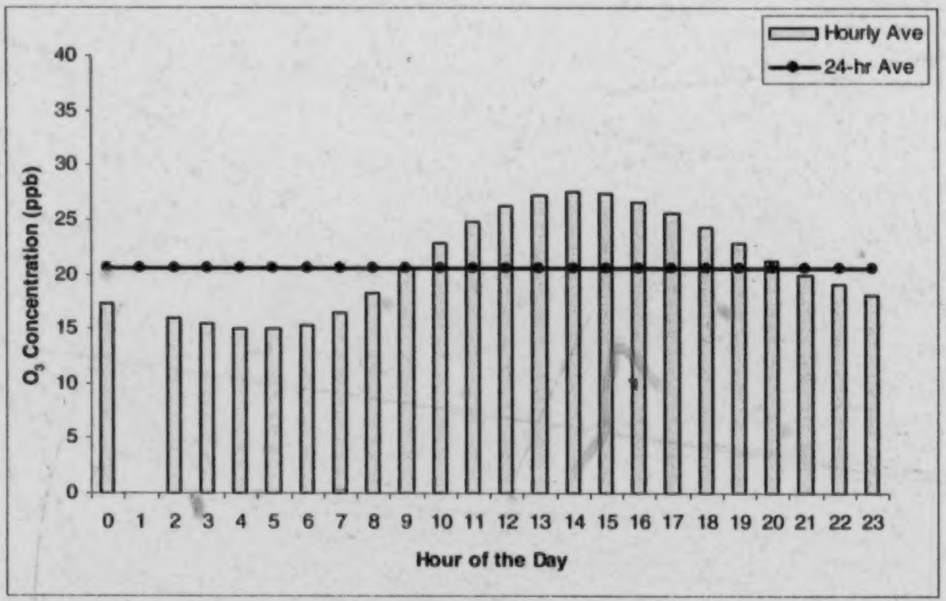

Figure 4-18: Diurnal hourly average concentration trends of O_3 (1999-2004) at Fort McKay air monitoring station

No observable day of the week patterns were found for ozone concentration at the Fort McKay station (Figure 4-19). This shows that the ozone formation is most likely due to factors which remain constant all week.

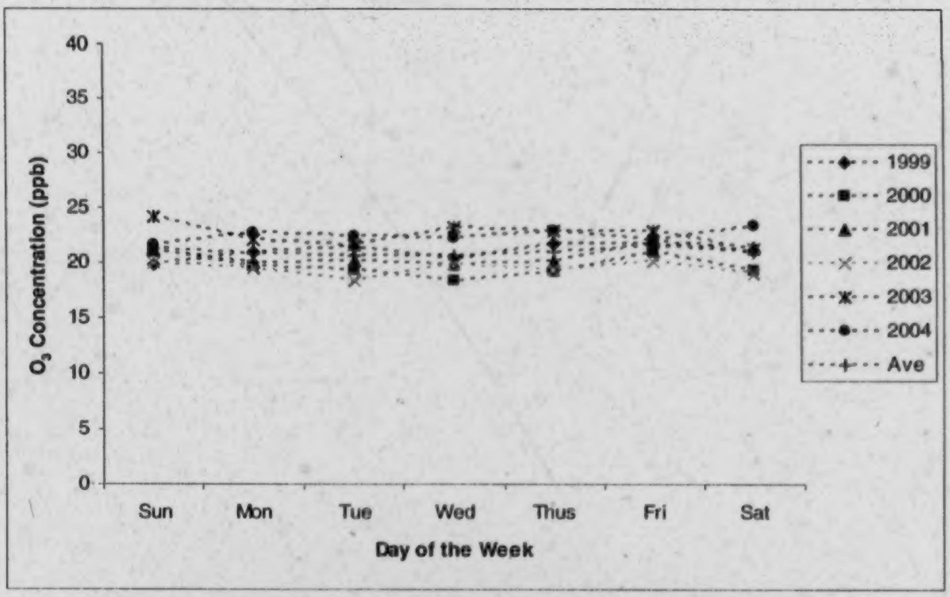

Figure 4-19: Day of the week trends of hourly average O_3 concentrations (1999-2004) at the Fort McKay air monitoring station

Figure 4-20 shows the seasonal patterns of ozone concentrations in Fort McKay. The ozone concentration in the months of March, April, and May were observed to be relatively higher than the rest of the year. The higher O_3 concentration in spring and early summer may reflect the impact of O_3 being transported from the stratosphere. Other reasons could be the higher photochemical reactions during the spring and summer when the conditions are more favorable for ozone formation.

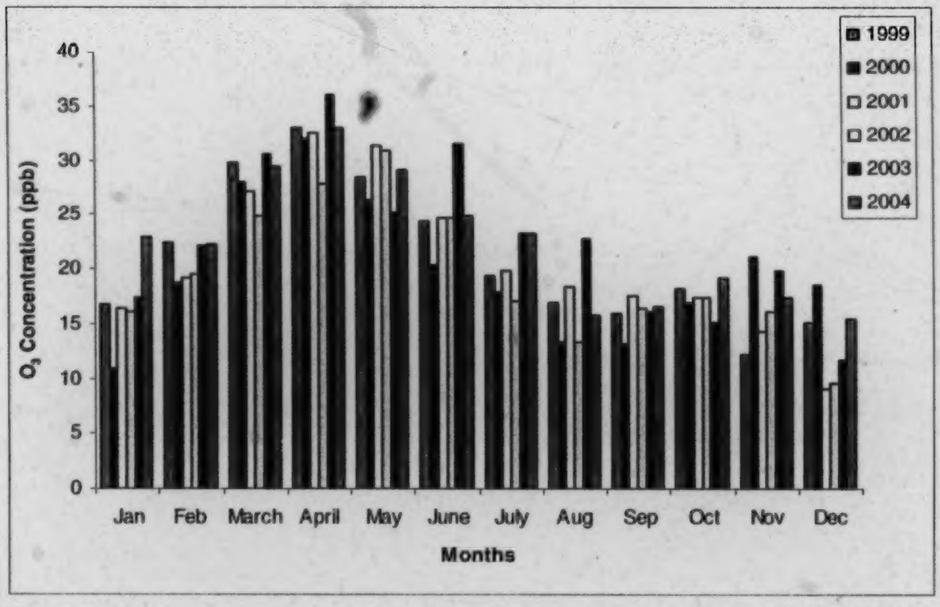

Figure 4-20: Monthly patterns of hourly average concentration values of O_3 (1999-2004) at the Fort McKay air monitoring station

4.2.2 Nitrogen Dioxide (NO_2)

Major sources of nitrogen oxides in Fort McKay are oil sands extraction and processing plants, followed by local vehicle use, and light industry (WBEA, 2003). No exceedences of the one-hour AAAQO of 212 ppb (400 μg/m^3) were observed between 1999 and 2004 (Figure 4-21). The maximum hourly average concentration recorded was 43 ppb (81 μg/m^3) in 2003. Annual averages for the 1999 to 2004 period ranged from 4 ppb (7 μg/m^3) to 7 ppb (13 μg/m^3).

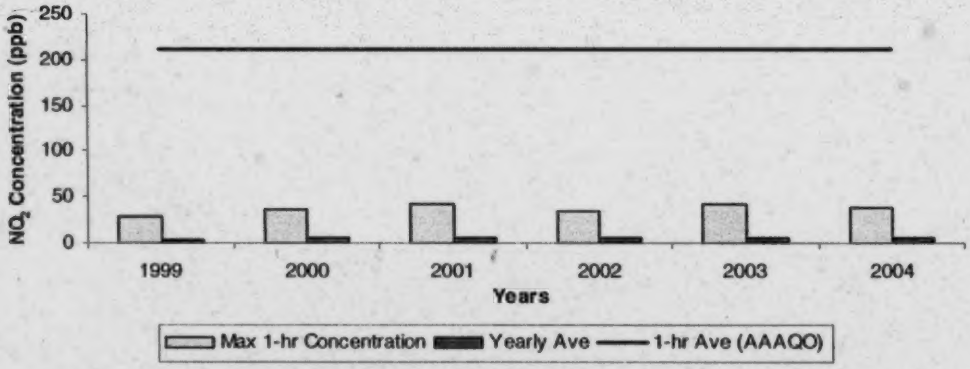

Figure 4-21: Yearly average and one-hour maximum NO$_2$ concentrations at Fort McKay air monitoring station

The diurnal hourly average concentrations for NO$_2$ showed no significant peaks during the day (Figure 4-22). In the morning between 7:00 to 9:00 hours, slightly higher NO$_2$ concentrations were observed. The NO$_2$ diurnal hourly average concentrations in Fort McKay were found to be significantly lower than the concentrations observed for the Edmonton Northwest station during the day.

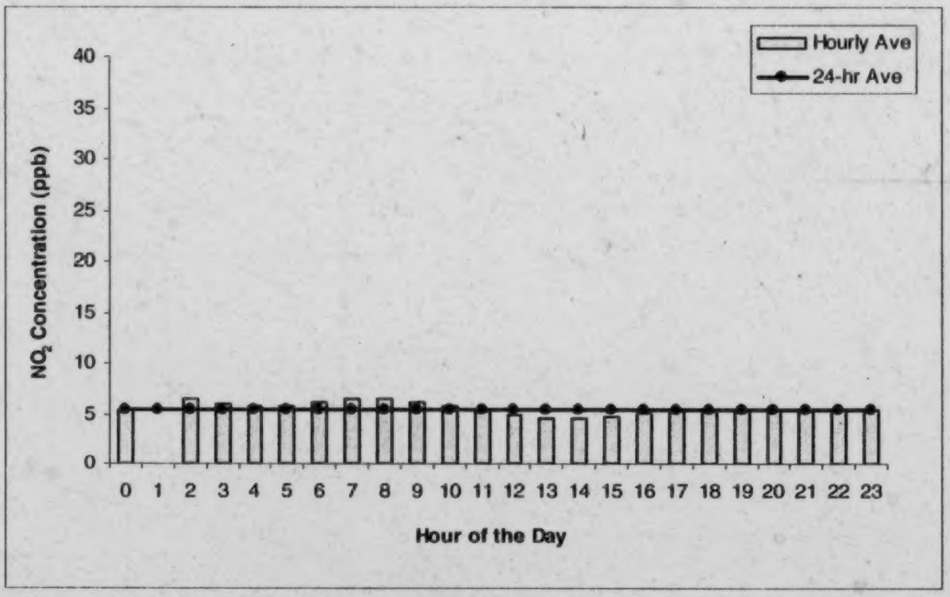

Figure 4-22: Diurnal hourly average concentration trends of NO$_2$ (1999-2004) at Fort McKay air monitoring station

No observable day of the week patterns were observed for NO_2 concentrations at the Fort McKay station as can be seen in Figure 4-23.

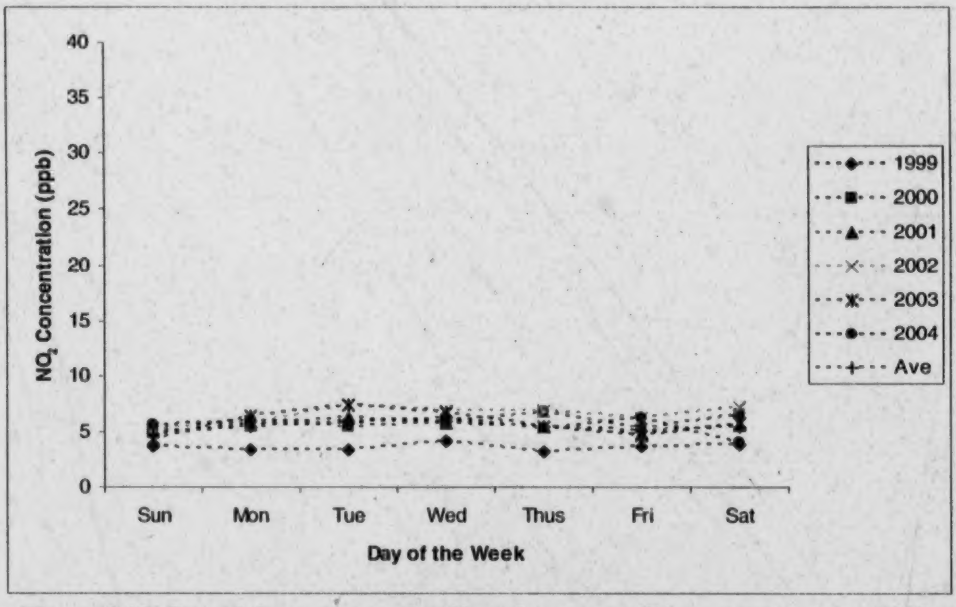

Figure 4-23: Day of the week trends of hourly average NO_2 concentrations (1999-2004) at the Fort McKay air monitoring station

The monthly patterns for NO_2 in Fort McKay show higher concentrations of NO_2 in the winter (November – February) than the rest of the year (Figure 4-24). The higher concentrations of NO_2 during the winter are due to temperature inversions which are common in winter (Myrick, 1995). These temperature inversions create a layer of cold stagnant air near the ground (especially in rural areas) which increases the persistence of pollutants in atmosphere. The lowest concentrations of NO_2 were observed in the summer (June and July).

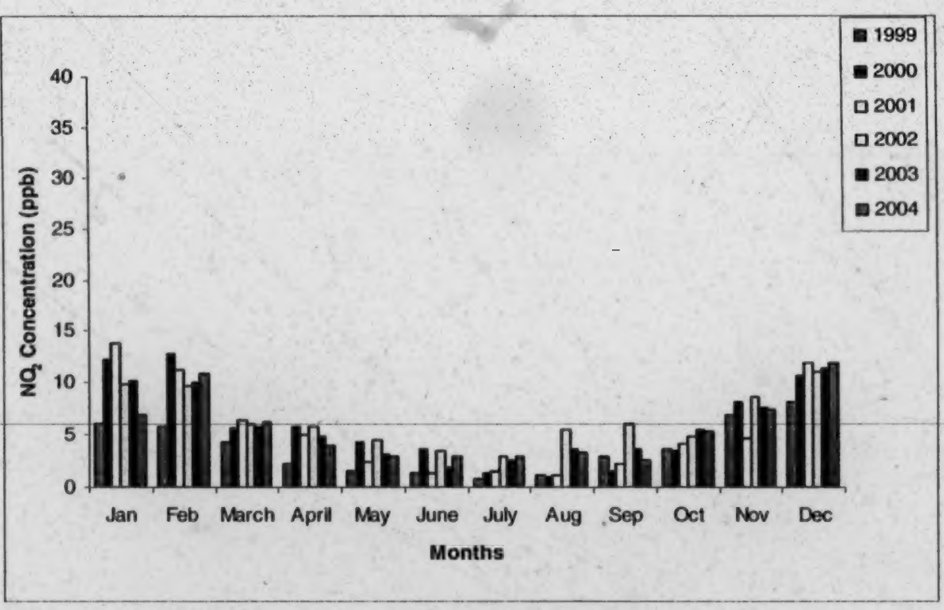

Figure 4-24: Monthly patterns of hourly average concentration values of NO_2 (1999-2004) at the Fort McKay air monitoring station

4.2.3 Fine Particulate Matter ($PM_{2.5}$)

Infrequent elevated hourly concentrations were recorded for $PM_{2.5}$ between 1999 and 2004. The highest one-hour concentration was recorded at 203 μg/m^3 in 2002 (Figure 4-25). The yearly average concentrations ranged from 4 to 7 μg/m^3.

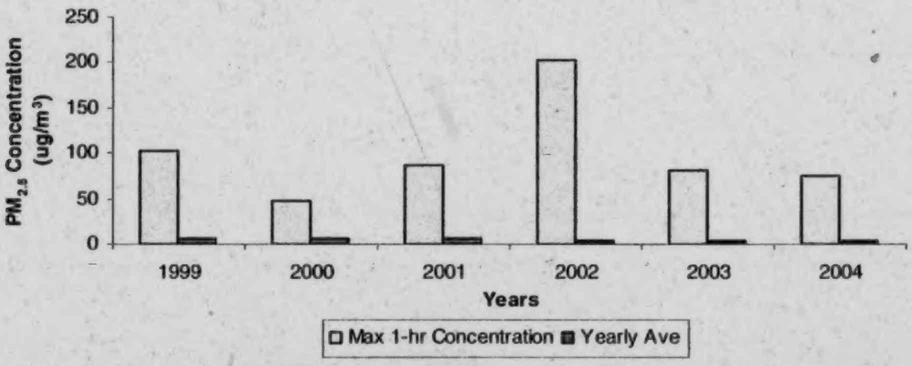

Figure 4-25: Yearly average and one-hour maximum $PM_{2.5}$ concentrations at Fort McKay air monitoring station

The diurnal hourly average concentrations for $PM_{2.5}$ at Fort McKay had a small peak during the day (Figure 4-26). This peak showed a steady decrease as the day progressed. The lowest values were observed during the night. The higher values of $PM_{2.5}$ during the day may reflect the higher direct emissions from anthropogenic sources or the production of fine particulate matter from secondary pollutants (various ambient pollutant gases) which are in higher concentrations during day time.

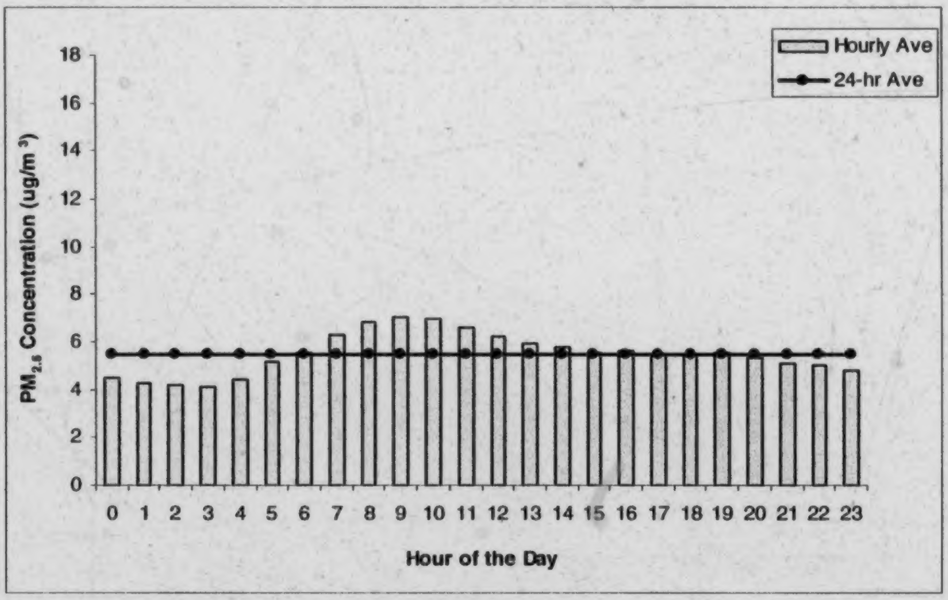

Figure 4-26: Diurnal hourly average concentration trends of $PM_{2.5}$ (1999-2004) at Fort McKay air monitoring station

No observable day of the week patterns were observed for $PM_{2.5}$ concentrations at Fort McKay station as can be seen in Figure 4-27.

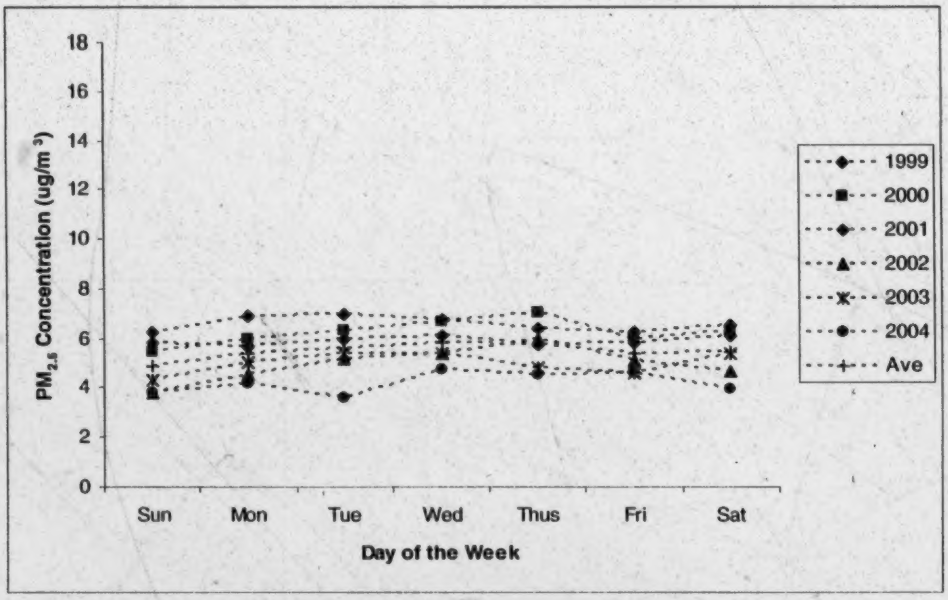

Figure 4-27: Day of the week trends of hourly average PM$_{2.5}$ concentrations (1999-2004) at the Fort McKay air monitoring station

The monthly patterns for PM$_{2.5}$ concentration did not show any observable peaks; however, hourly average monthly values for summer were found to be slightly higher than other months (Figure 4-28). Cheng et al. (2000) observed the same patterns for PM$_{2.5}$ and concluded that rural PM$_{2.5}$ concentrations in Alberta did not show significant seasonal differences. Although the production of fine particles are known to be higher in the summer season (Gillani et al., 1981 as cited in Cheng et al., 2000), higher mixing heights during summer seasons counteracts the increase due to chemical transformation (Myrick and Hunt, 1994).

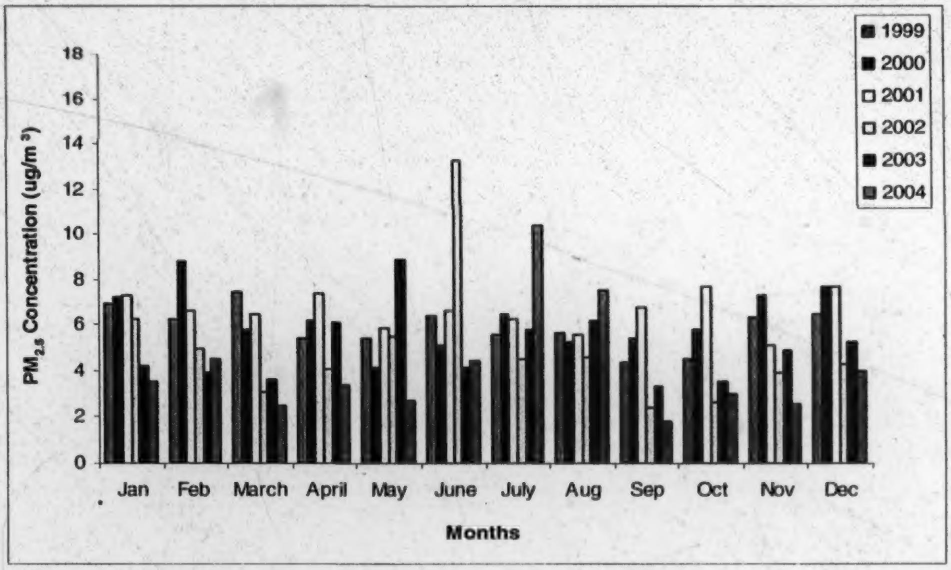

Figure 4-28: Monthly patterns of hourly average concentration values of $PM_{2.5}$ (1999-2004) at the Fort McKay air monitoring station

4.2.4 Total Hydrocarbons (THC)

The main anthropogenic sources of THC in Fort McKay are fugitive emissions in the form of reactive hydrocarbons, VOCs, and methane from the oil sands industries (WBEA, 2003). There are no Alberta ambient air quality guidelines for THC. The maximum one-hour average concentration recorded between 1999 and 2004 was 11 ppm in 2003 and the annual average concentration was found to be 1.9 ppm (Figure 4-29).

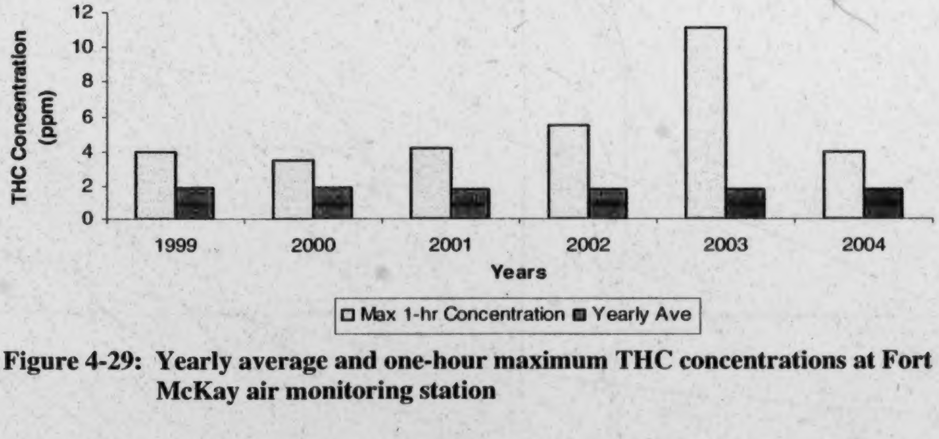

Figure 4-29: Yearly average and one-hour maximum THC concentrations at Fort McKay air monitoring station

No observable differences in the THC concentrations for diurnal (Figure 4-30), day of the week (Figure 4-31), or monthly (Figure 4-32) patterns were observed.

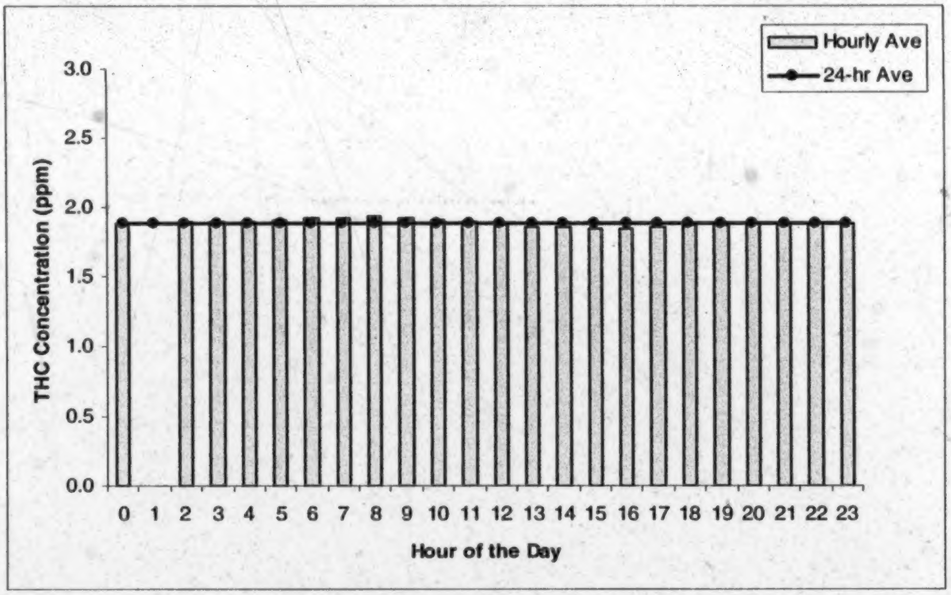

Figure 4-30: Diurnal hourly average concentration trends of THC (1999-2004) at Fort McKay air monitoring station

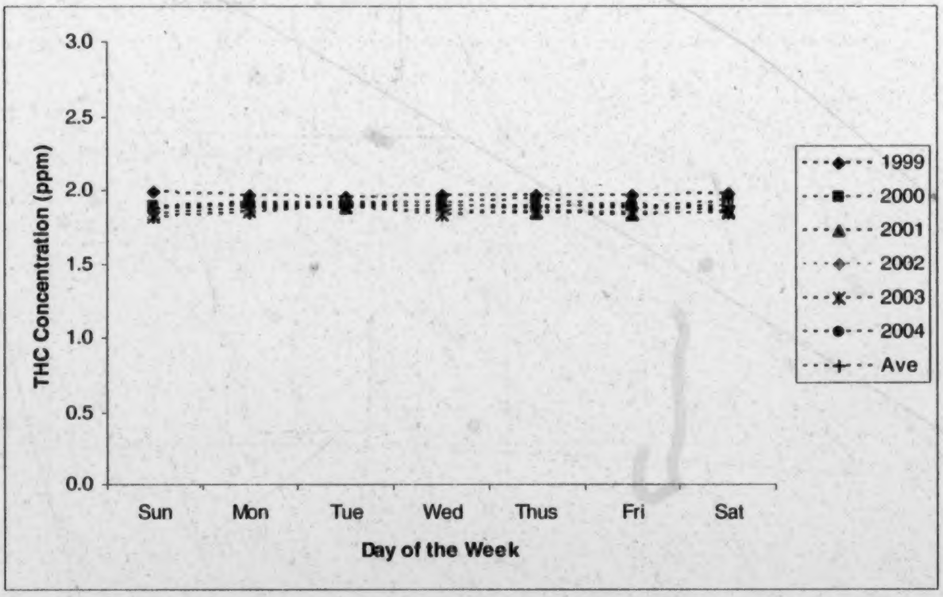

Figure 4-31: Day of the week trends of hourly average THC concentrations (1999-2004) at the Fort McKay air monitoring station

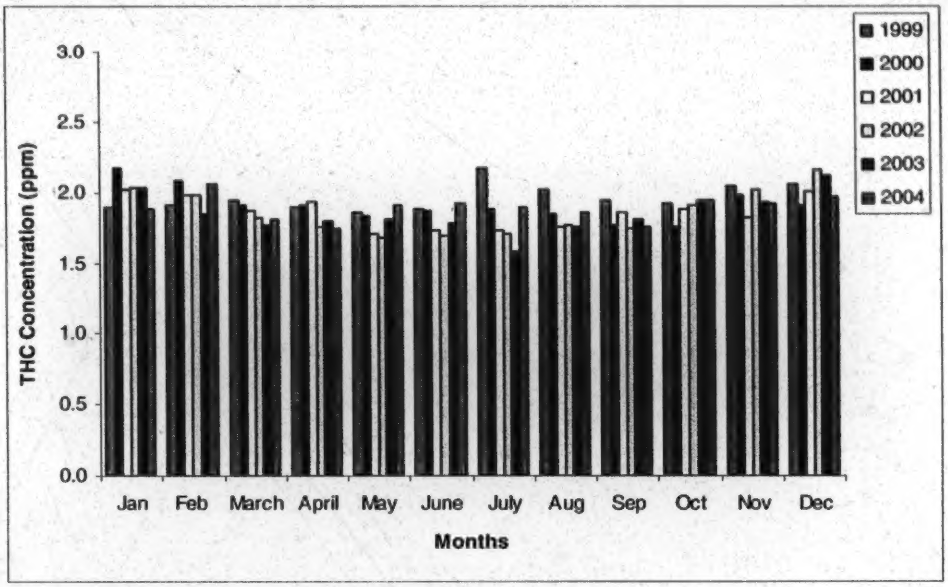

Figure 4-32: Monthly patterns of hourly average concentration values of THC (1999-2004) at the Fort McKay air monitoring station

4.3 Short Term Temporal Trends for Edmonton

The cumulative frequency distribution plots for each yearly data set of pollutants (O_3, NO_2, CO and $PM_{2.5}$) were assessed for various percentiles between the 50th and the 98th. The concentration-based and frequency-based bench marks were identified for the respective percentiles which were used for trend analysis. The cumulative frequency distribution plots of baseline years for each pollutant (O_3, NO_2, CO and $PM_{2.5}$) at the Edmonton Northwest station are given below (Figure 4-33 to 4-36). The cumulative frequency distribution plots of the remaining years for the selected pollutants at Edmonton Northwest air monitoring station are provided in Appendix 7.3 – 7.6.

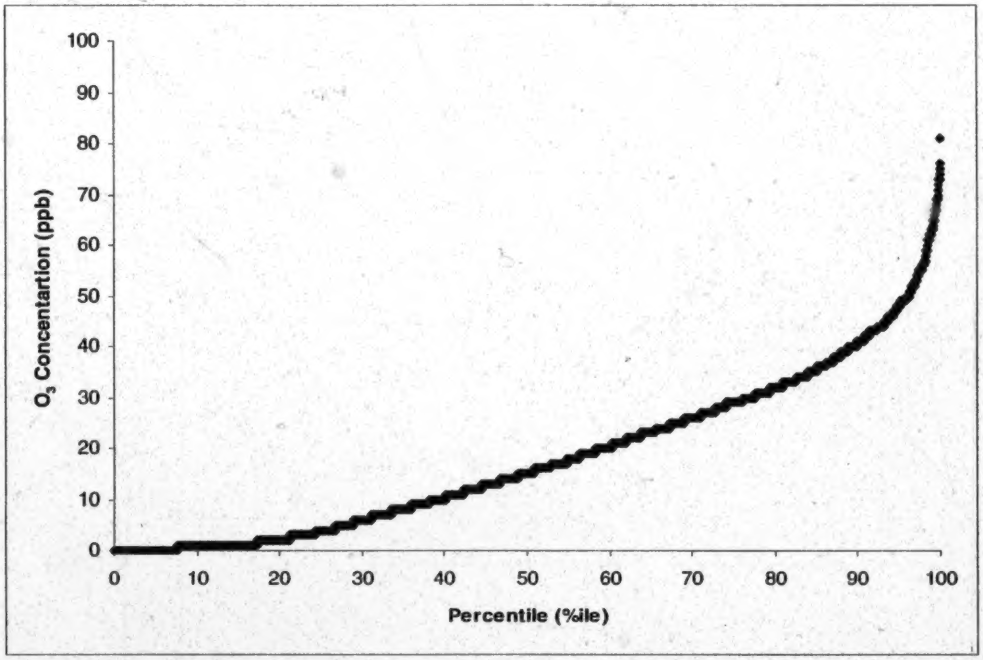

Figure 4-33: Cumulative frequency distribution for O_3 - 1997 (Edmonton)

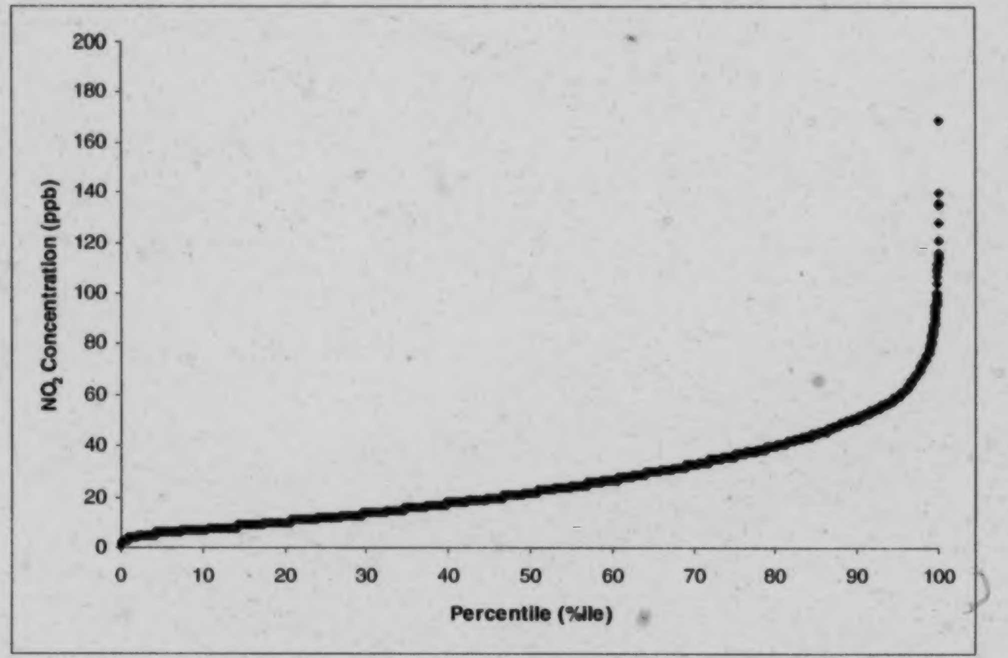

Figure 4-34: Cumulative frequency distribution for NO_2 - 1997 (Edmonton)

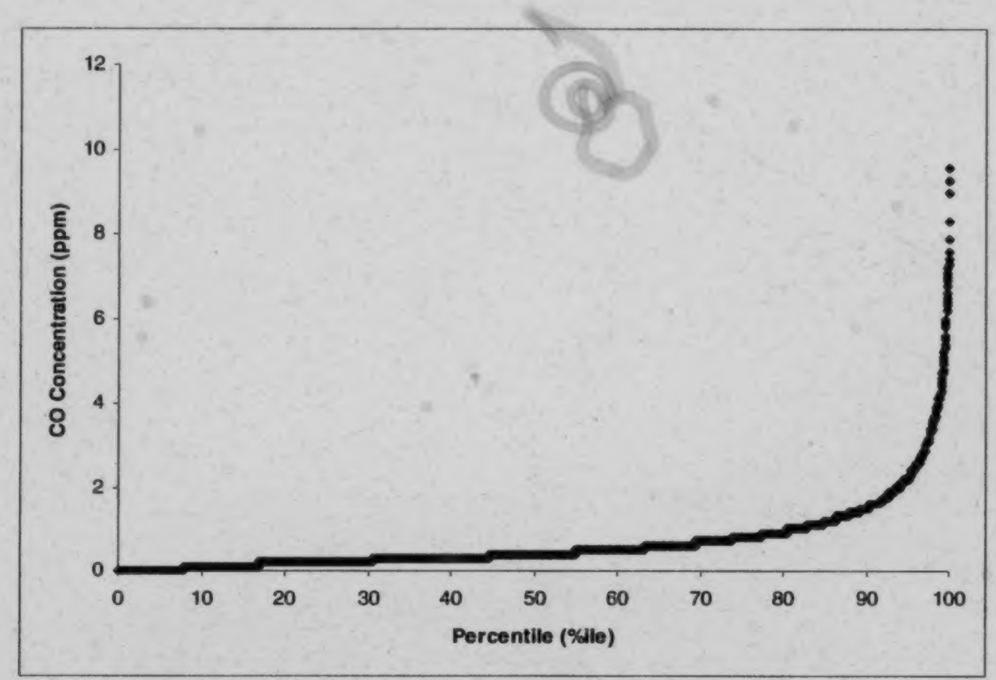

Figure 4-35: Cumulative frequency distribution for CO - 1997 (Edmonton)

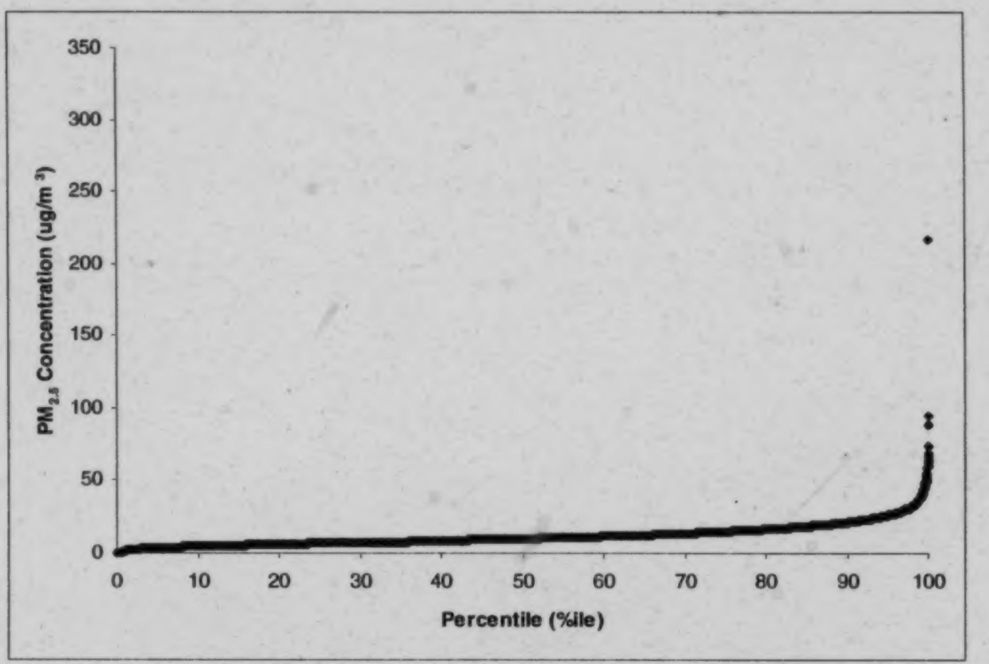

Figure 4-36: Cumulative frequency distribution for $PM_{2.5}$ - 1999 (Edmonton)

Benchmark data for each pollutant were analyzed for short-term temporal trends using both concentration-based and frequency-based approaches. Results indicated that both approaches yielded similar outcomes; therefore, only concentration-based benchmark results for the 50th, 65th, 80th, 90th, 95th, and 98th percentiles are presented. Short term trends for the Edmonton Northwest station using frequency-based benchmarks are presented in Appendix 7.16

4.3.1 Ozone (O_3)

Short-term O_3 concentration trends for the Edmonton Northwest station are depicted in Figure 4-37. No clear visual trends are observable for any measured percentiles. It can be seen in Figure 4-37 that the O_3 concentration decreased in 1999 and 2000 and increased again in 2003. The slope of the trend lines for the different percentiles were not found to be significantly different from 0 based on Student t-test and the ANOVA test ($\alpha = 0.05$). Several studies (Qin et al., 2004; William et al., 1983; Yang and Miller, 2002) have reported decreasing trends in ground-level urban O_3 concentrations. These studies reported that these decreases were most likely due to regulatory emission control of human activities. Decreases were not found for the O_3 concentration observed at the Edmonton Northwest station.

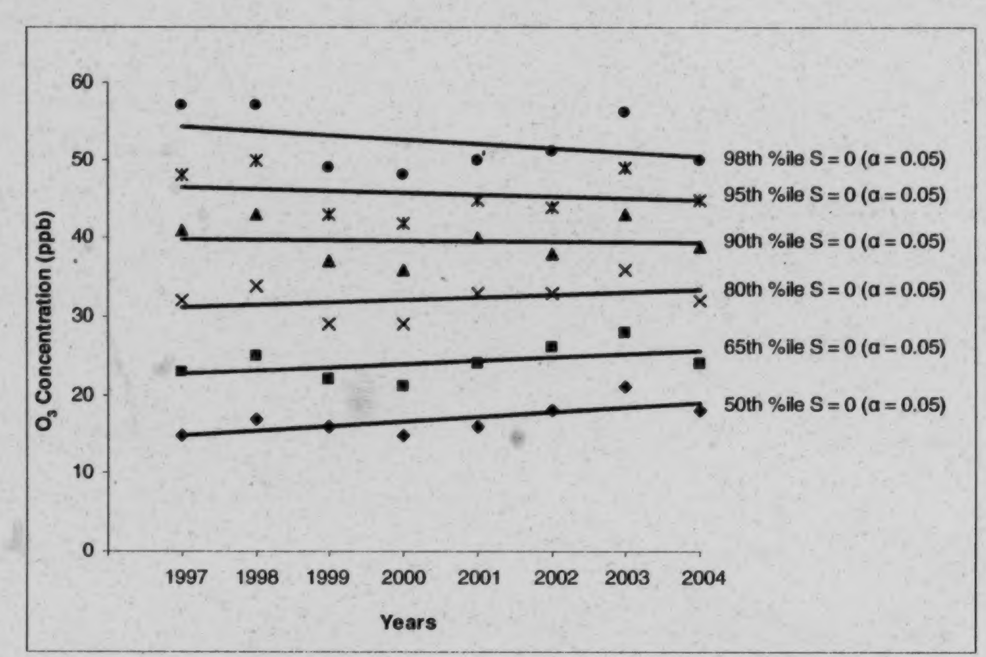

Figure 4-37: Edmonton Northwest air quality concentration trends for O_3

4.3.2 Nitrogen Dioxide (NO_2)

With respect to ambient NO_2 trend analysis, there appeared to be a slight decreasing trend observed for both concentration-based and frequency-based benchmarks at the higher percentiles (Figure 4-38); however, hypothesis testing indicated that slope of the best fit lines were not significantly different from 0 based on Student t-test and the ANOVA test ($\alpha = 0.05$). NO_2 is largely a secondary pollutant formed by the oxidation of

NO. According to the USEPA (2002), major anthropogenic sources of NO in urban areas are automobiles, the remainder of which is NO_2. The Edmonton Northwest station was located in an area where road transport is considered to be a dominant source of NO, and thus a primary source for NO_2. It was concluded that no significant change (trend) was observed in NO_2 concentrations during the period of study at this station.

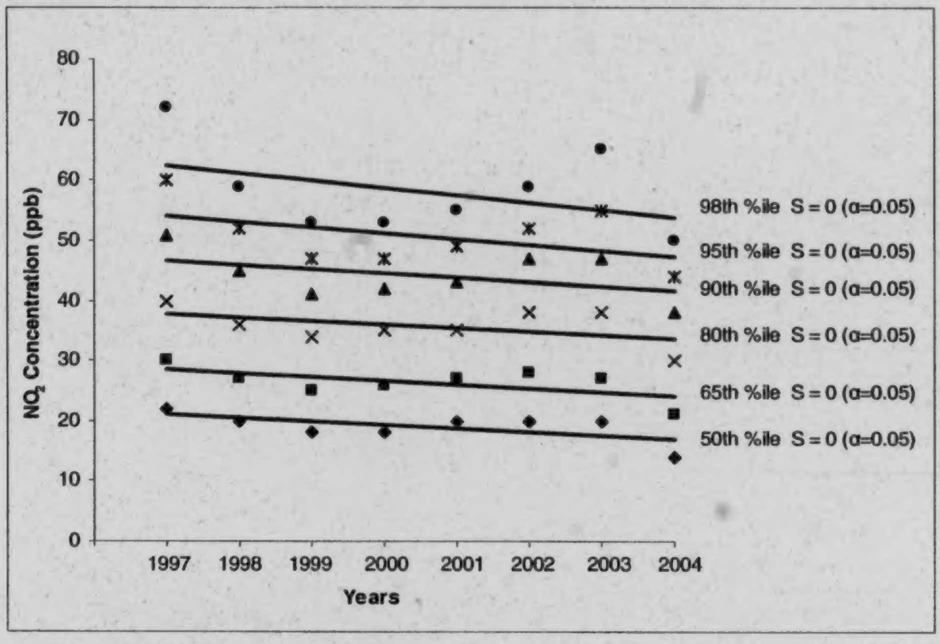

Figure 4-38: Edmonton Northwest air quality concentration trends for NO_2

4.3.3 Carbon Monoxide (CO)

Figure 4-39 visually indicates consistent downward trends for each CO concentration percentile. Hypothesis testing indicated that slope of the best fit lines for 65th to 98th percentiles was less than 0 based on Student t-test and the ANOVA test ($\alpha = 0.05$); however, the slope of the best fit line at the 50th percentile was found to be equal to 0 ($\alpha = 0.05$). Similar results were obtained for frequency based benchmarks (Appendix 7.16).

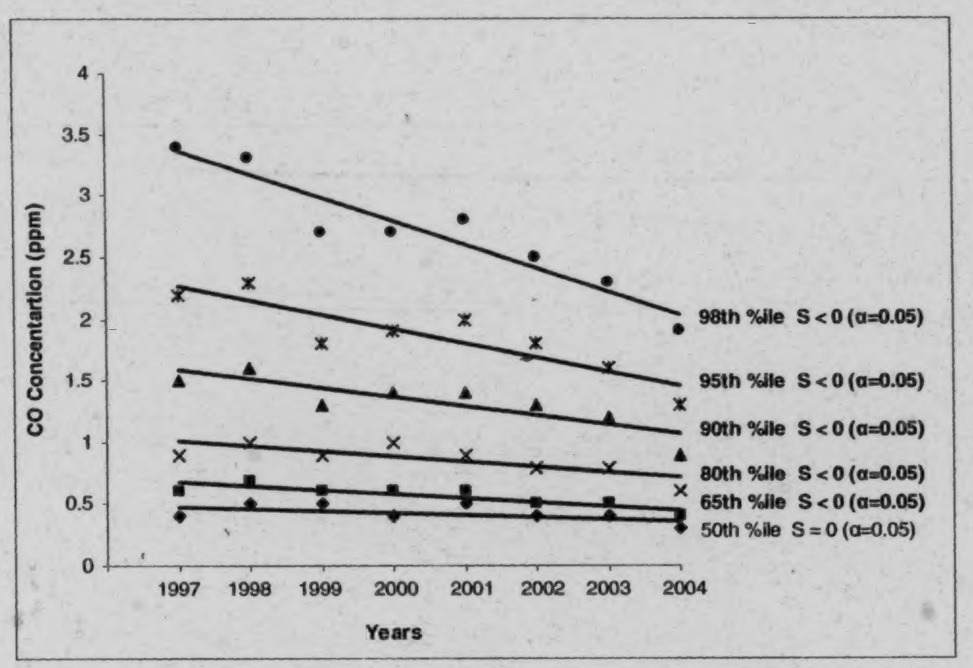

Figure 4-39: Edmonton Northwest air quality concentration trends for CO

In big cities, as much as 95% of all CO emissions may come from automobile exhaust (USEPA, 2001). Based on emission profiles, carbon monoxide was linked by Myrick and Hunt (1996) to transportation as a major urban air pollutant source in Alberta. Statistically significant deceasing CO concentration trends indicated an overall improvement in air quality at this monitoring location, despite an approximately 16% increase in the number of private vehicles in Edmonton between 1997 and 2004 (City of Edmonton, 2006b). This decreasing trend may be related to better emission controls from automobiles. Specifically, Environment Canada transportation emission inventory modeling for Alberta, as reported by Chamberland (2005), projected consistent overall decreases in CO emissions from automobiles during the same time period. These decreases were anticipated to be due to improved engine performance and fuel quality. Model results provided by Chamberland (2005) predicted decreases in CO emissions from vehicles starting in 1970 and continuing decreases despite a projected increase in the number of vehicles on roads in Alberta.

4.3.4 Fine Particulate Matter ($PM_{2.5}$)

In the case of $PM_{2.5}$ there appeared to be a consistent decreasing trend for each $PM_{2.5}$ concentration percentile, as can be seen in Figure 4-40; however, hypothesis testing indicated that the slopes of the best fit lines were less than 0 only for the lower to moderate percentiles (50th to 80th) based on Student t-test and the ANOVA test (α = 0.05). The slopes of the best fit lines were equal to 0 for higher percentiles (90th to 98th) ($\alpha = 0.05$). Similar results were obtained for frequency based benchmarks (Appendix 7-16).

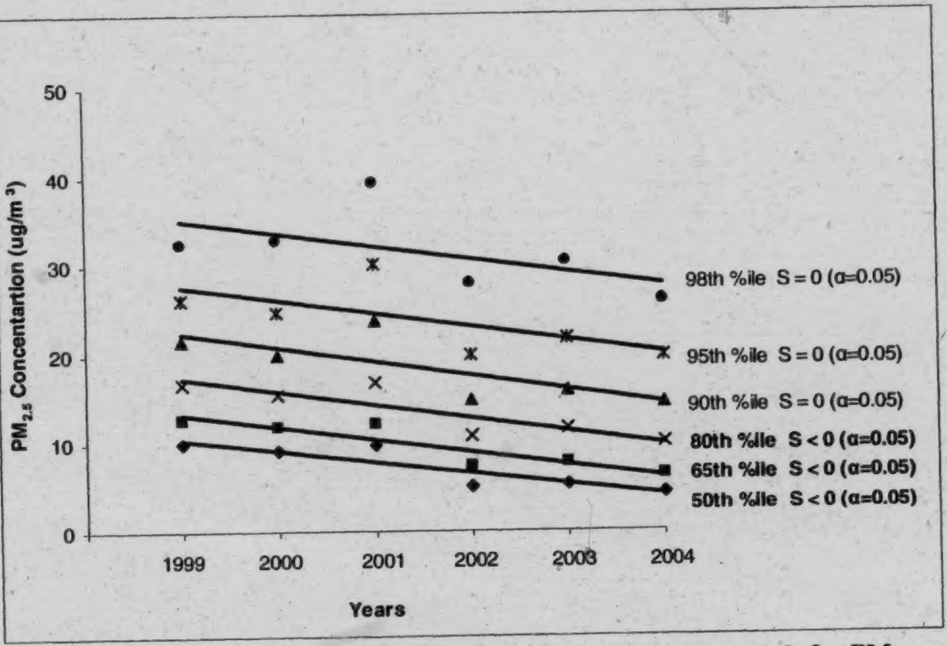

Figure 4-40: Edmonton Northwest air quality concentration trends for $PM_{2.5}$

It can be assumed that as the Edmonton Northwest station was located in a busy traffic area, road vehicles may have had a significant contribution to the fine particulate matter concentrations recorded at this station. The peak rush hour traffic flow adjacent to the station (127 Street – 132 Avenue) showed a slight decrease in vehicle volume from 2000 to 2004 at peak morning and evening hours (City of Edmonton. 2006b).

4.4 Short Term Temporal Trends for Fort McKay

The concentration-based and frequency-based benchmarks for each pollutant (O_3, NO_2, $PM_{2.5}$ and THC) for various percentiles (50th to 98th) were assessed from the cumulative frequency distribution plots of each yearly data set. The cumulative frequency distribution plots of baseline years for each pollutant are provided below (Figure 4-41 to 4-44). The cumulative frequency distribution plots of the remaining years for selected pollutants at the Fort McKay air monitoring station are provided in Appendix 7.7 – 7.10.

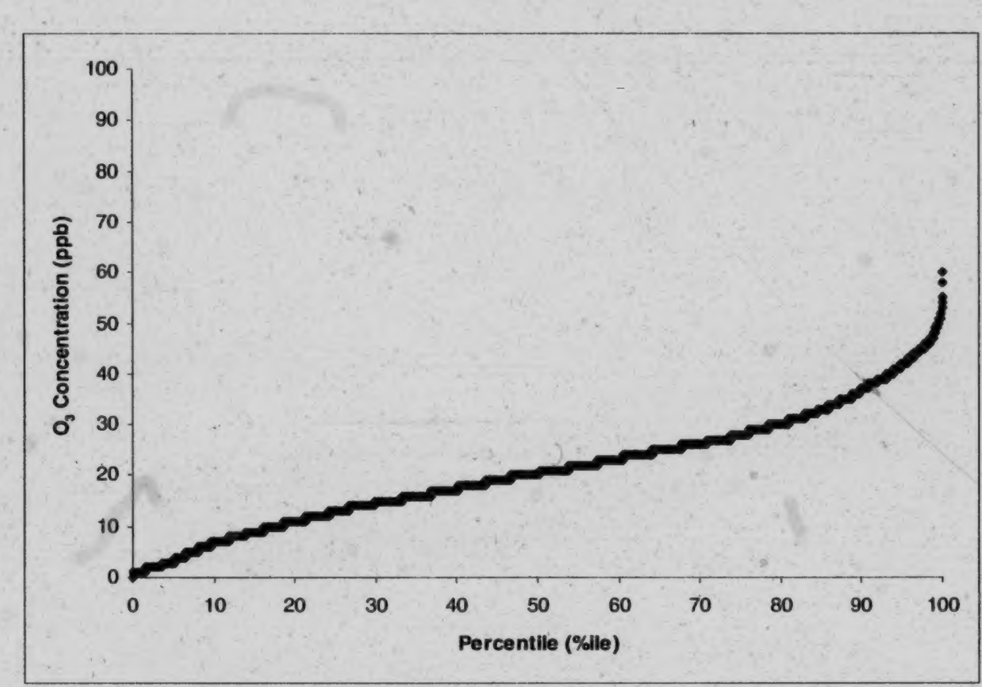

Figure 4-41: Cumulative frequency distribution for O_3 - 1999 (Fort McKay)

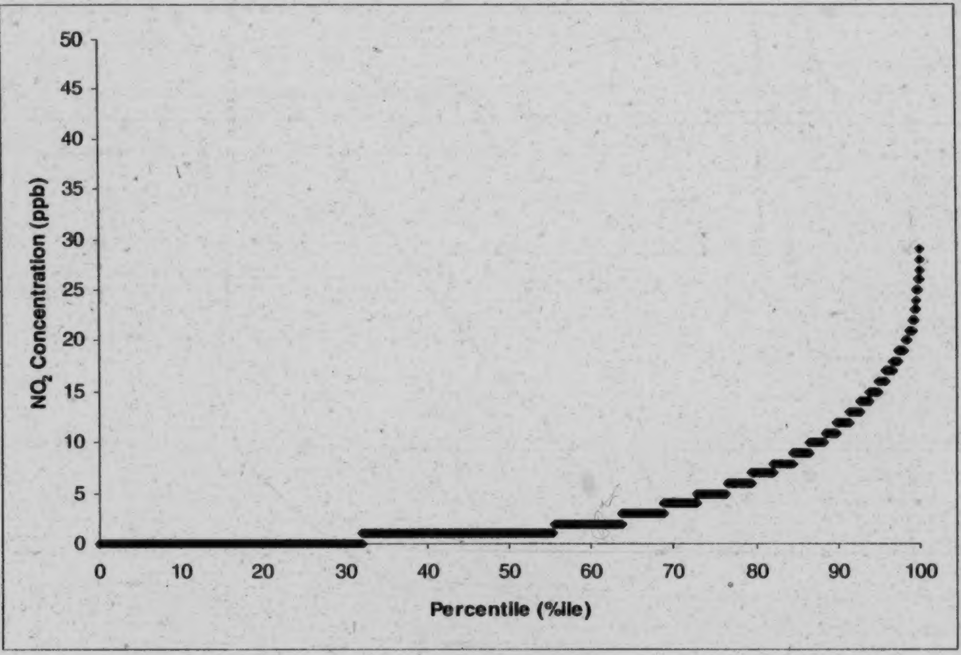

Figure 4-42: Cumulative frequency distribution for NO$_2$ - 1999 (Fort McKay)

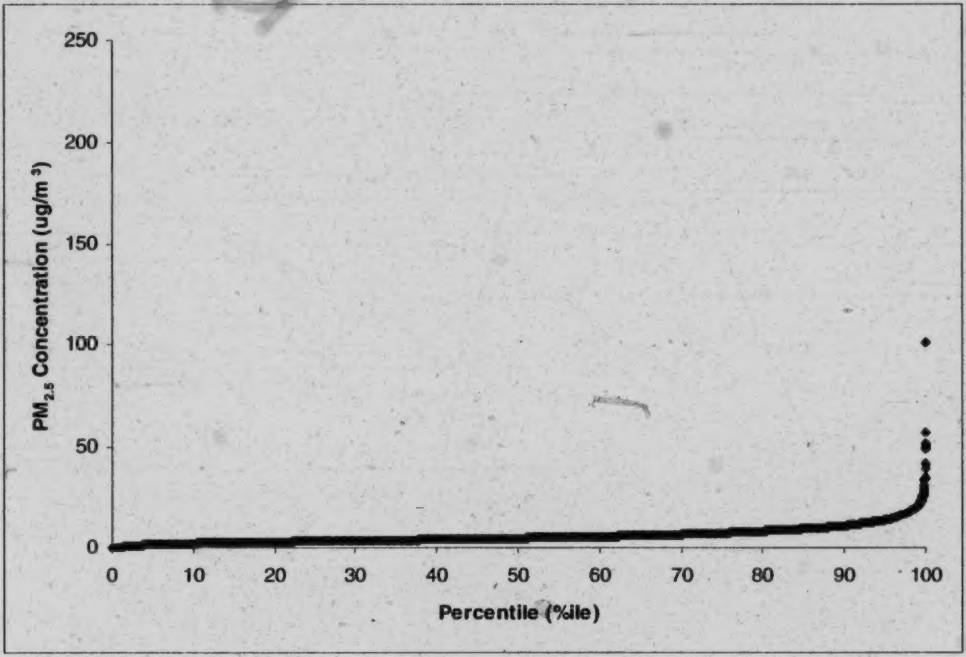

Figure 4-43: Cumulative frequency distribution for PM$_{2.5}$ – 1999 (Fort McKay)

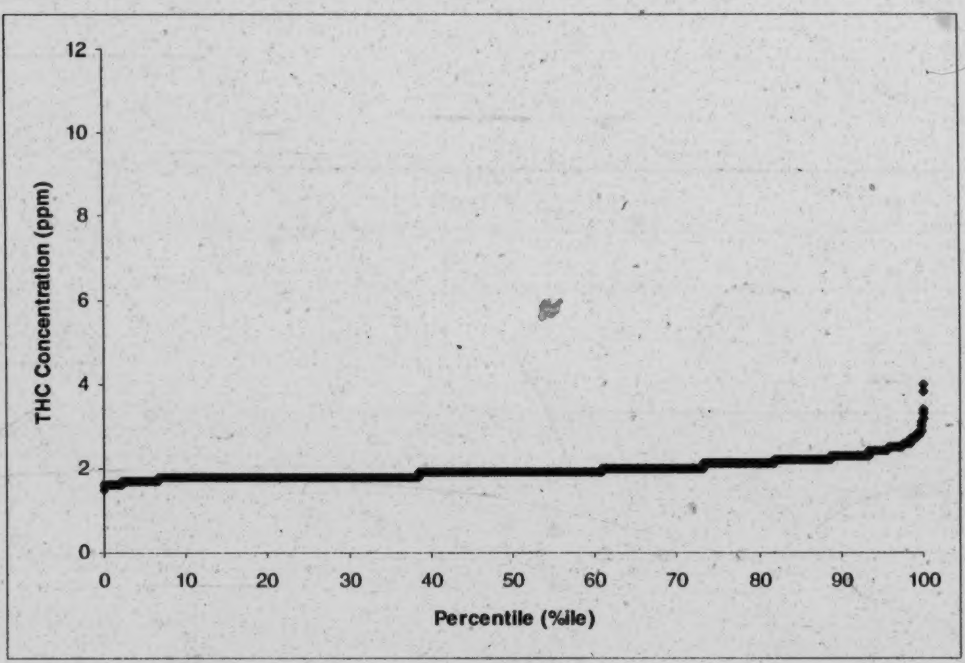

Figure 4-44: Cumulative frequency distribution for THC – 1999 (Fort McKay)

Benchmark data identified from cumulative frequency distribution plots for O_3, NO_2, $PM_{2.5}$ and THC were analyzed for short-term temporal trends using both concentration-based and frequency-based benchmark approaches. Both approaches yielded similar results, therefore only concentration-based benchmark results for the 50th, 65th, 80th, 90th, 95th, and 98th percentiles are presented. Short term trends for the Fort McKay air monitoring station using frequency-based benchmarks are presented in Appendix 7.17.

4.4.1 Ozone

Figure 4-45 visually indicates a slightly increasing trend for every O_3 concentration percentile over the six-year period of study; however, when the slopes of the best fit lines were tested for statistical significance, none of the slopes were found to be significantly different from 0 based on Student t-test and the ANOVA test ($\alpha = 0.05$).

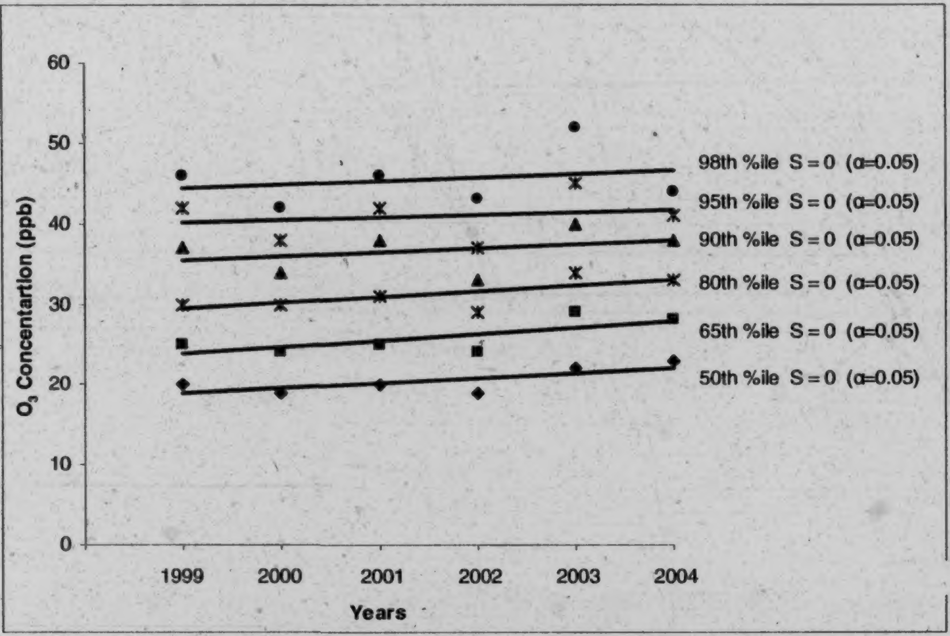

Figure 4-45: Fort McKay air quality concentration trends for O_3

4.4.2 Nitrogen Dioxide (NO_2)

Figure 4-46 visually indicates slightly increasing trends for the lowest to the highest NO_2 concentration percentiles studied. When slopes of the best fit lines were tested for statistical significance, no change was indicated for any of the percentiles, except the 98th percentile. The slope of the trend line for the 98th percentile indicated a statistically significant increasing trend ($\alpha = 0.05$) over the six-year period of study.

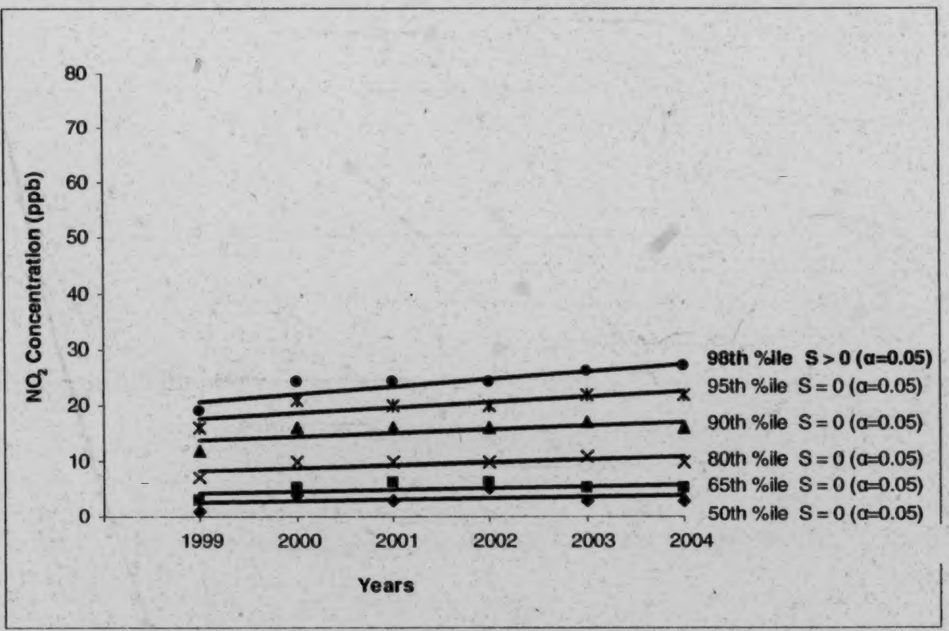

Figure 4-46: Fort McKay air quality concentration trends for NO_2

4.43 Fine Particulate Matter ($PM_{2.5}$)

Figure 4-47 depicts the trends for various concentration percentiles. When the slopes of the best fit lines were tested for statistical significance, different results were found for different percentiles. A statistically significant decreasing trend was found at the 50th percentile, while a statistically significant increasing trend was found at the 98th percentile ($\alpha = 0.05$). Hypothesis testing failed to indicate the presence of trends for the rest of the percentiles. These results are generally interpreted as being inconclusive for indicating any type of change occurring over the six-year period of study.

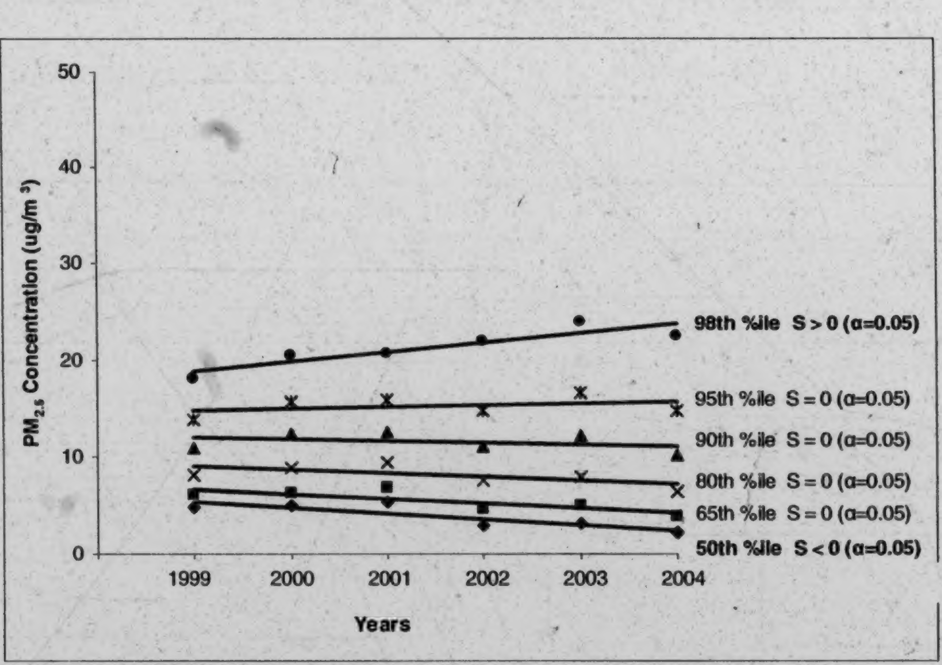

Figure 4-47. Fort McKay air quality concentration trends for $PM_{2.5}$

4.4.4 Total Hydrocarbons (THC)

Figure 4-48 visually indicates the slightly increasing and slightly decreasing trends for the lowest to the highest THC concentration percentiles studied. When slope of the best fit lines were tested for statistical significance, no change was indicated for any of the percentiles, except the 90th percentile. The slope of the trend line for the 90th percentile indicated a statistically significant decreasing trend ($\alpha = 0.05$) over the six-year period of study.

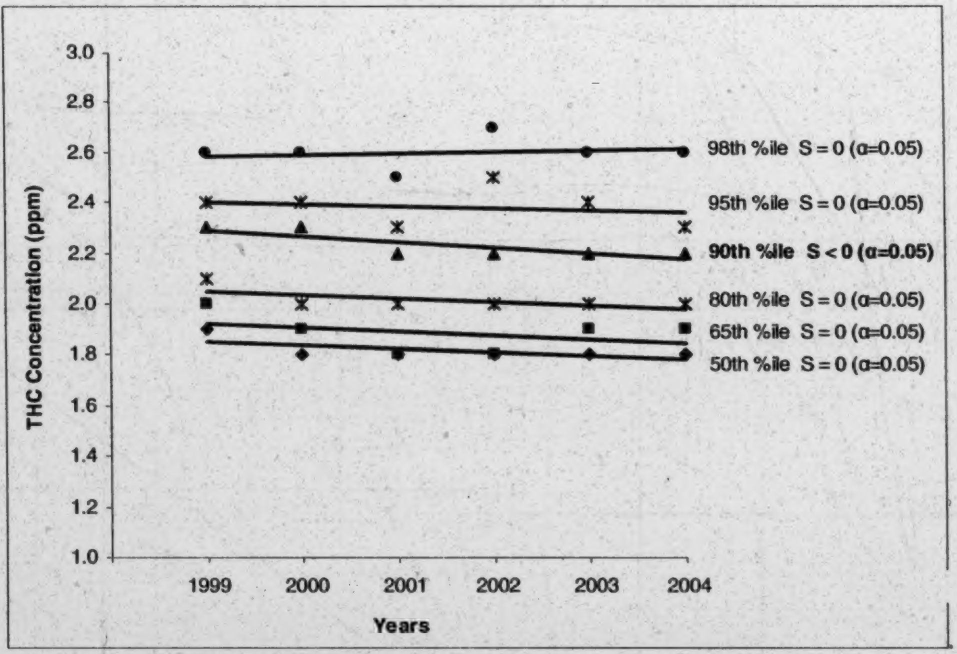

Figure 4-48: Fort McKay air quality concentration trends for THC

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The focus of this study was to examine the short-term changes (trends) in the concentration of various ambient pollutants including CO, NO_2, O_3, and $PM_{2.5}$ in Edmonton, Alberta and NO_2, O_3, $PM_{2.5}$, and THC in Fort McKay, Alberta over the previous eight years. A further comparison of diurnal (hours of the day), day of the week, and seasonal (monthly) patterns were also done during the study.

Diurnal patterns for ozone at the Edmonton Northwest station showed a peak in the afternoon, while the peaks for NO_2, CO and $PM_{2.5}$ diurnal patterns were observed during early morning and evening time. The afternoon diurnal peak of ozone may relate to higher photochemical reactions. The diurnal peaks for NO_2, CO and $PM_{2.5}$ were observed to be during or immediately following rush hour traffic.

Diurnal trends for ozone at the Fort McKay station showed similar patterns to Edmonton with a peak in the afternoon. The diurnal patterns for $PM_{2.5}$ showed only morning peaks. The morning peak for NO_2 was very small and almost negligible. The diurnal hourly average concentrations for NO_2 and $PM_{2.5}$ at Fort McKay were found to be significantly less than the diurnal hourly average concentrations observed at the Edmonton Northwest station. THC did not show any trends for the hour of the day.

Day of the week patterns for ozone at Edmonton Northwest station did not show any change in the concentration values during the week; however, the concentration of NO_2, CO, and $PM_{2.5}$ were found to be slightly higher on weekdays than on weekends. No observable day of week patterns were found for O_3, NO_2, $PM_{2.5}$, and THC at the Fort McKay station.

A similar seasonal ozone peak was observed for Edmonton and Fort McKay during spring and early summer. Seasonal peaks for NO_2 and CO in Edmonton, and NO_2 in Fort McKay showed peaks during the winter season. $PM_{2.5}$ for Edmonton and Fort McKay did not show any seasonal trends.

Short term temporal trends were analyzed for selected pollutants by using concentration-based and frequency-based benchmark methods. Ambient NO_2 and O_3 concentrations did not show any statistically significant short-term trends over an eight-year period (1997 to 2004) in Edmonton ($\alpha = 0.05$). Statistically significant decreasing trends were observed for ambient CO and $PM_{2.5}$ concentrations over the same time period ($\alpha = 0.05$). $PM_{2.5}$ trends were statistically significant only for lower to moderate percentiles (50^{th} to 80^{th}). None of the pollutants examined at Fort McKay, O_3, NO_2, $PM_{2.5}$, and THC, showed any statistically significant trends over the period of study ($\alpha = 0.05$).

The period of study over which the trends were examined was short (less than a decade) and changes or lack thereof observed do not necessarily provide an indication of what may happen over the long term. The results do generally support that, despite increasing economic and other development activity in Edmonton and continued oil sands expansion surrounding the community of Fort McKay, air quality conditions have remained unchanged or have improved during the last six to eight years.

Execution of this study yielded considerations that should be addressed if a similar study were performed. The main recommendation would be to increase the time period for trend analysis to at least 10 years. Historical ambient air monitoring data for the city of Edmonton and Fort McKay were taken from a single continuous monitoring station in their respective areas. Ambient monitoring data from more than one monitoring station could yield a better understanding of air quality conditions over time in these areas.

CHAPTER 6: REFERENCES

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CHAPTER 7: APPENDICES

APPENDIX 7.1 Data Characteristics of pollutants including % completeness, % non-detects, Maximum, Minimum and Median for Edmonton Northwest station

Table 7-1: Data Characteristics of O_3 (1997 – 2004) - Edmonton Northwest

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppb)	Maximum (ppb)	Median (ppb)
1997	99.4	7.7	0	81	15
1998	98.7	3.8	0	88	17
1999	99.5	3.4	0	75	16
2000	98.9	2.2	0	66	15
2001	98.3	6.4	0	71	16
2002	99.7	4	0	94	18
2003	99.4	2.3	0	91	21
2004	99.2	2.1	0	73	18

Table 7-2: Data Characteristics of NO_2 (1997 – 2004) - Edmonton Northwest

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppb)	Maximum (ppb)	Median (ppb)
1997	93.3	0	1	169	22
1998	95.8	0.1	0	158	20
1999	98.1	0.01	0	79	18
2000	99.3	0.01	0	94	18
2001	99.5	0	2	104	20
2002	95.6	0.1	0	138	20
2003	99.4	0	1	109	20
2004	99.3	0	1	82	14

Table 7-3: Data Characteristics of CO (1997 – 2004) - Edmonton Northwest

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppm)	Maximum (ppm)	Median (ppm)
1997	98.1	7.9	0	9.6	0.4
1998	98.7	3	0	10.2	0.5
1999	99.6	0.04	0	9.3	0.5
2000	99.2	1.14	0	7.7	0.4
2001	98.3	0.53	0	11.2	0.5
2002	98.9	0.96	0	10.1	0.4
2003	99.5	0.31	0	5.9	0.4
2004	99.3	0.01	0	6.6	0.3

Table 7-4: Data Characteristics of $PM_{2.5}$ (1999 – 2004) - Edmonton Northwest

Year	% Completeness	% of Non-detects	Range		
			Minimum (µg/m^3)	Maximum (µg/m^3)	Median (µg/m^3)
1999	99.9	0.5	0	216.5	10
2000	99.5	0.82	0	231.3	9.3
2001	98.1	0.51	0	261.3	9.8
2002	98.8	6.39	0	307.5	5.3
2003	99.5	4.65	0	97.1	5.5
2004	99.0	6.48	0	102.7	4.4

APPENDIX 7.2 Data Characteristics of pollutants including % completeness, % non-detects, Maximum, Minimum and Median for Fort McKay station

Table 7-5: Data Characteristics of O_3 (1999 – 2004) - Fort McKay

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppb)	Maximum (ppb)	Median (ppb)
1999	94.5	0.01	0	60	20
2000	94.8	0.08	0	60	19
2001	94.6	1.04	0	58	20
2002	94.8	0.36	0	61	19
2003	95.7	0.64	0	84	22
2004	95.1	0.25	0	70	23

Table 7-6: Data Characteristics of NO_2 (1999 – 2004) - Fort McKay

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppb)	Maximum (ppb)	Median (ppb)
1999	91.3	32	0	29	1
2000	94	15.45	0	36	4
2001	93.9	15.45	0	42	3
2002	94.2	8	0	35	5
2003	93.24	20.3	0	43	3
2004	92.1	15.3	0	38	3

Table 7-7: Data Characteristics of $PM_{2.5}$ (1999 – 2004) - Fort McKay

Year	% Completeness	% of Non-detects	Range		
			Minimum (μg/m^3)	Maximum (μg/m^3)	Median (μg/m^3)
1999	97.3	1	0	101.5	4.8
2000	98.8	1	0	47.6	4.9
2001	98.6	1.11	0	86.4	5.3
2002	95.1	13.9	0	203.5	3
2003	97.2	15.9	0	80.9	3.1
2004	98.6	6.72	0	74.9	2.2

Table 7-8: Data Characteristics of THC (1999 – 2004) - Fort McKay

Year	% Completeness	% of Non-detects	Range		
			Minimum (ppm)	Maximum (ppm)	Median (ppm)
1999	93.4	0	1.5	4	1.9
2000	92.5	0	1.5	3.5	1.8
2001	94.2	0	1.6	4.2	1.8
2002	94.6	0	1.4	5.5	1.8
2003	94.2	0	1.4	11.1	1.8
2004	94.7	0	1.5	4	1.8

APPENDIX 7.3 Cumulative Frequency Distribution for Ozone - Edmonton Northwest (1998 – 2004)

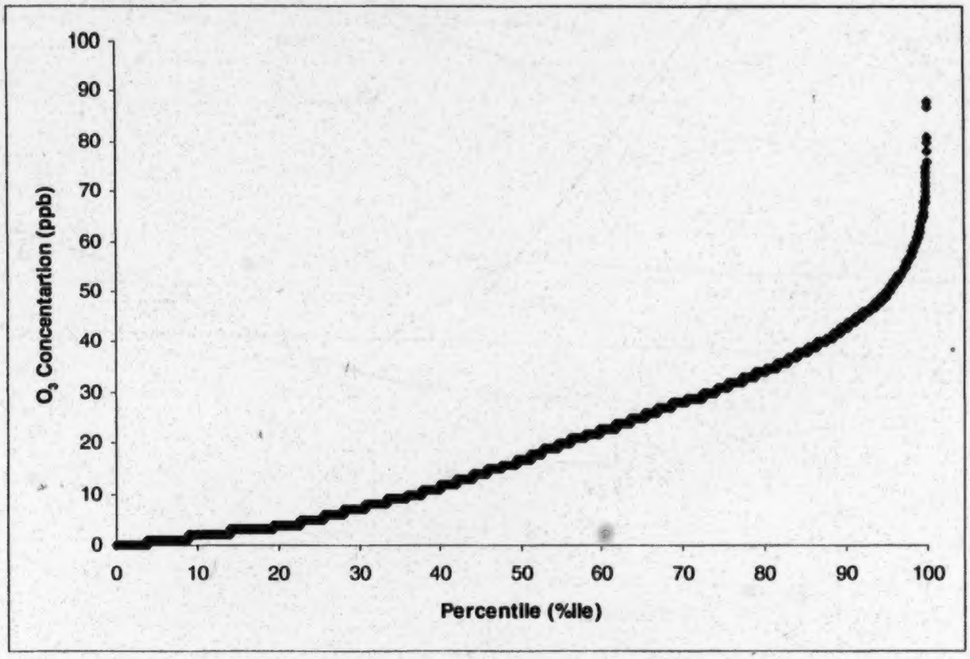

Figure 7-1: Cumulative frequency distribution for Ozone - 1998 (Edmonton)

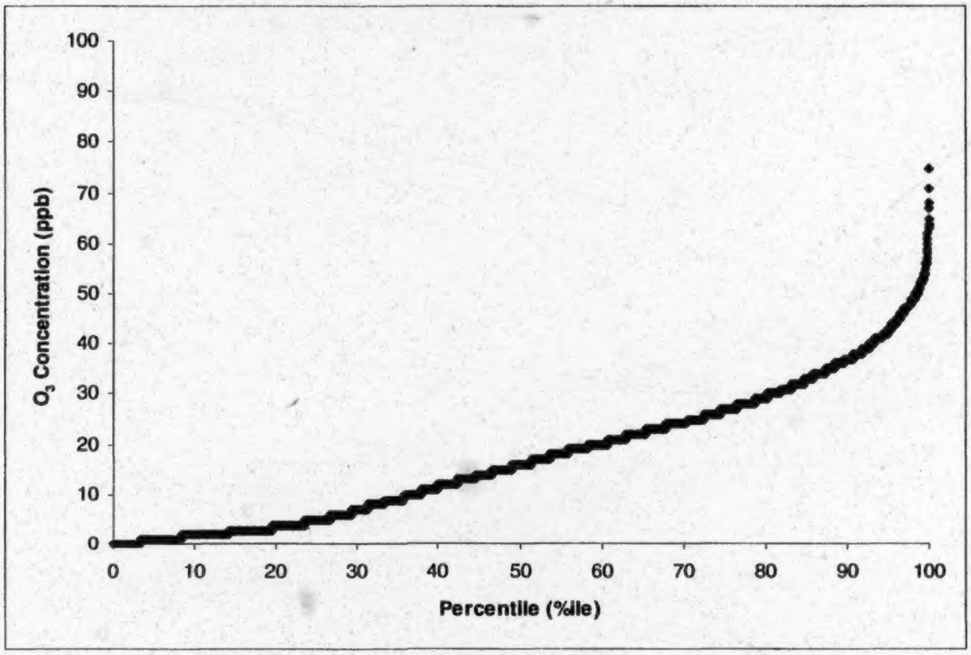

Figure 7-2: Cumulative frequency distribution for Ozone - 1999 (Edmonton)

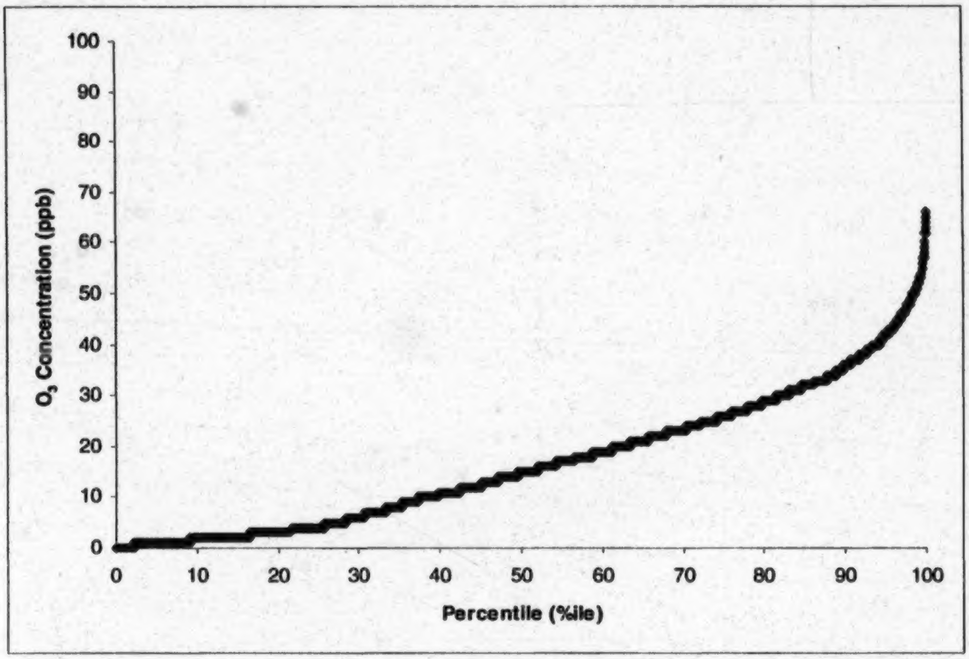

Figure 7-3: Cumulative frequency distribution for Ozone - 2000 (Edmonton)

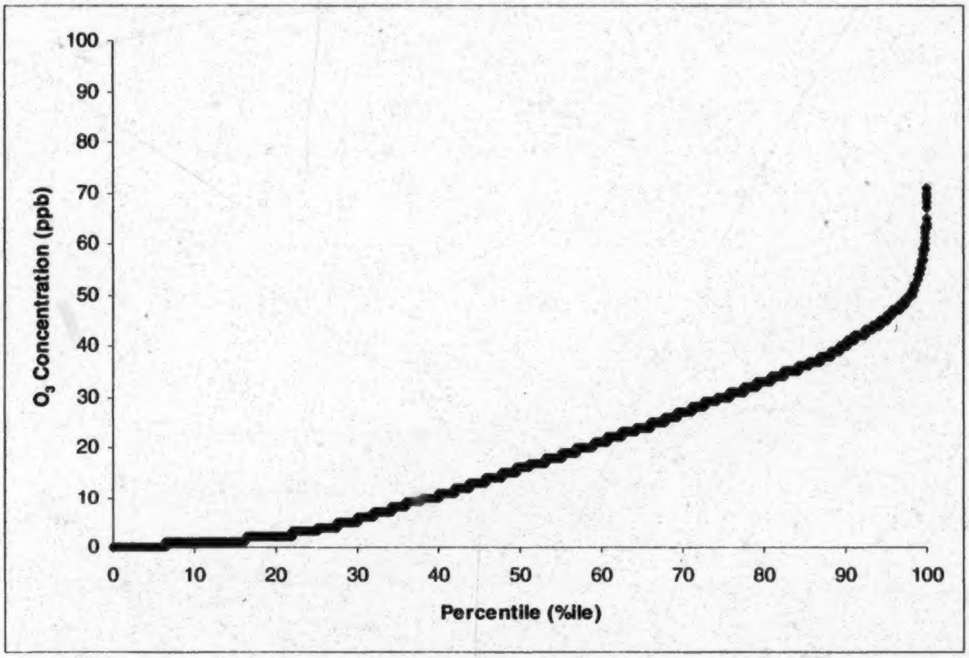

Figure 7-4: Cumulative frequency distribution for Ozone - 2001 (Edmonton)

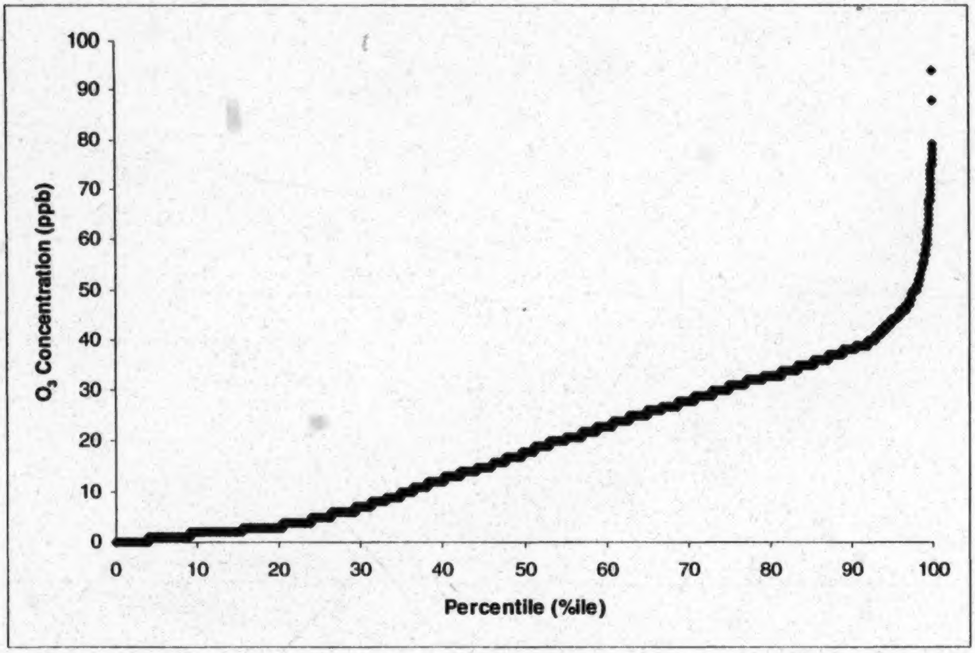

Figure 7-5: Cumulative frequency distribution for Ozone - 2002 (Edmonton)

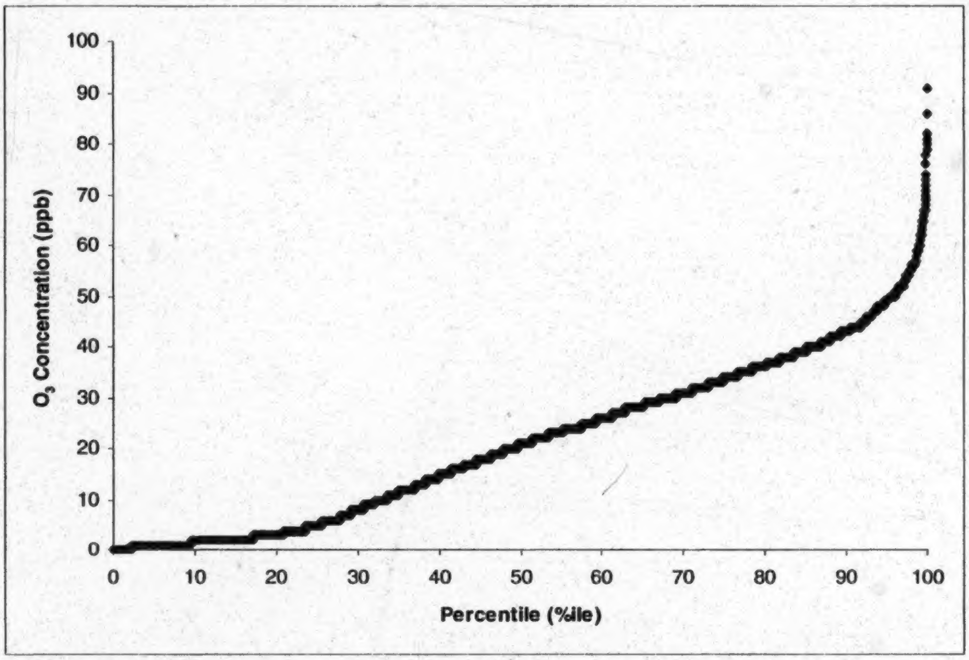

Figure 7-6: Cumulative frequency distribution for Ozone - 2003 (Edmonton)

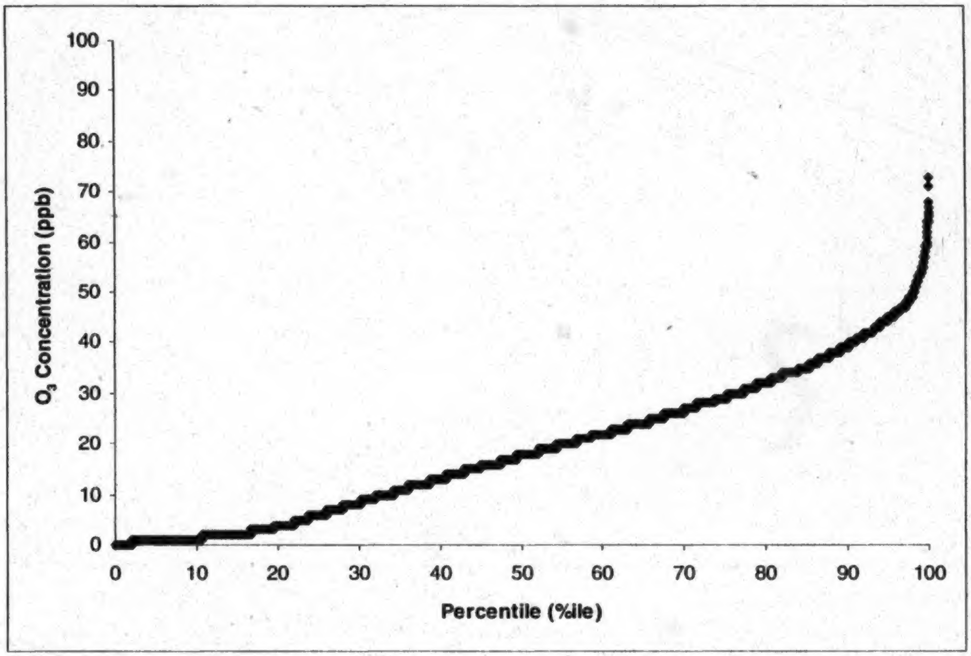

Figure 7-7: Cumulative frequency distribution for Ozone - 2004 (Edmonton)

APPENDIX 7.4 Cumulative Frequency Distribution for NO_2 - Edmonton Northwest (1998 – 2004)

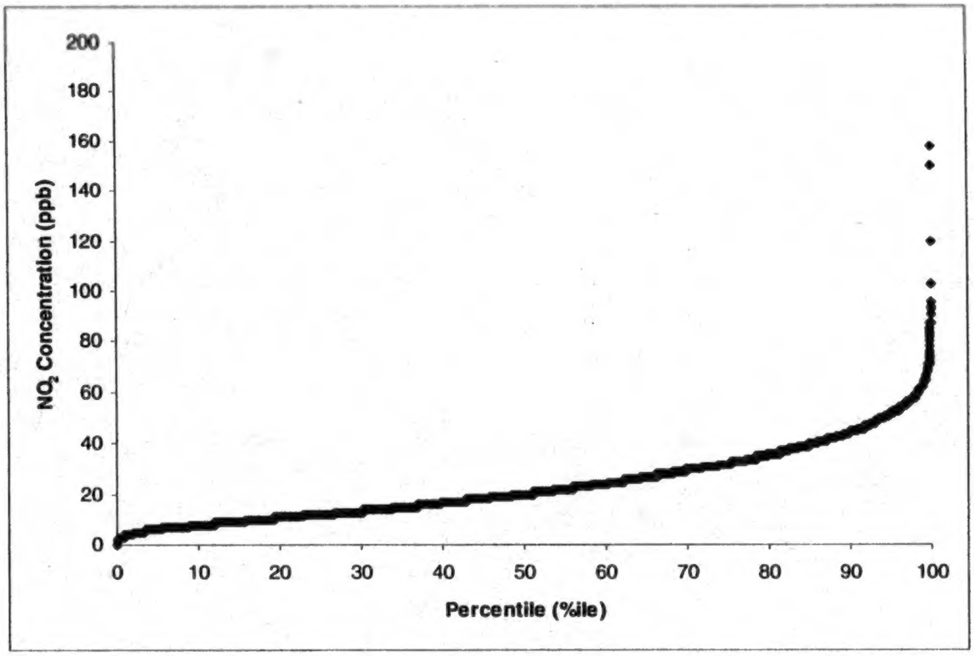

Figure 7-8: Cumulative frequency distribution for NO_2 - 1998 (Edmonton)

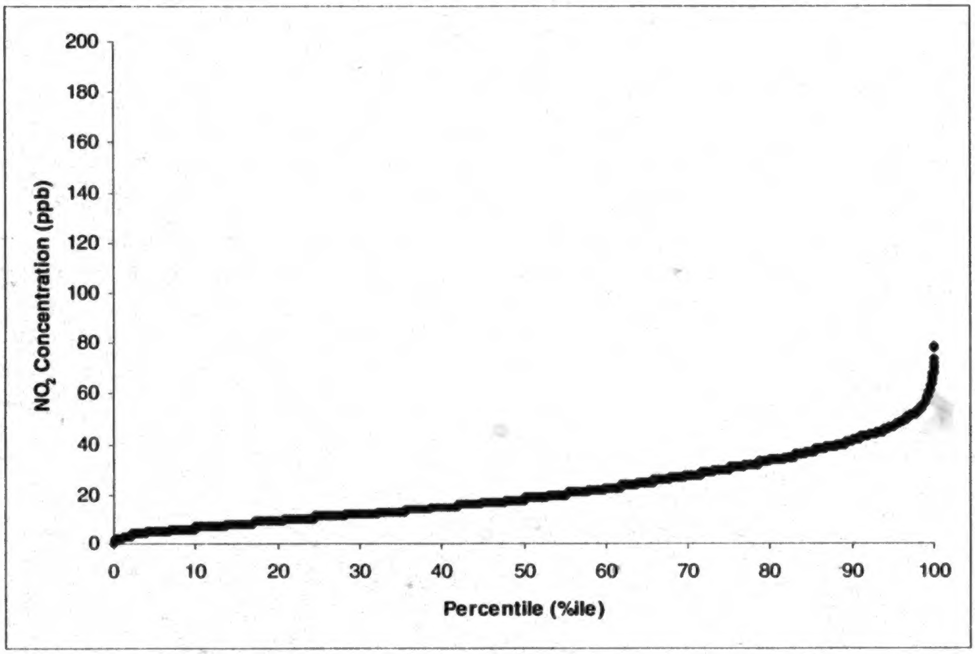

Figure 7-9: Cumulative frequency distribution for NO_2 - 1999 (Edmonton)

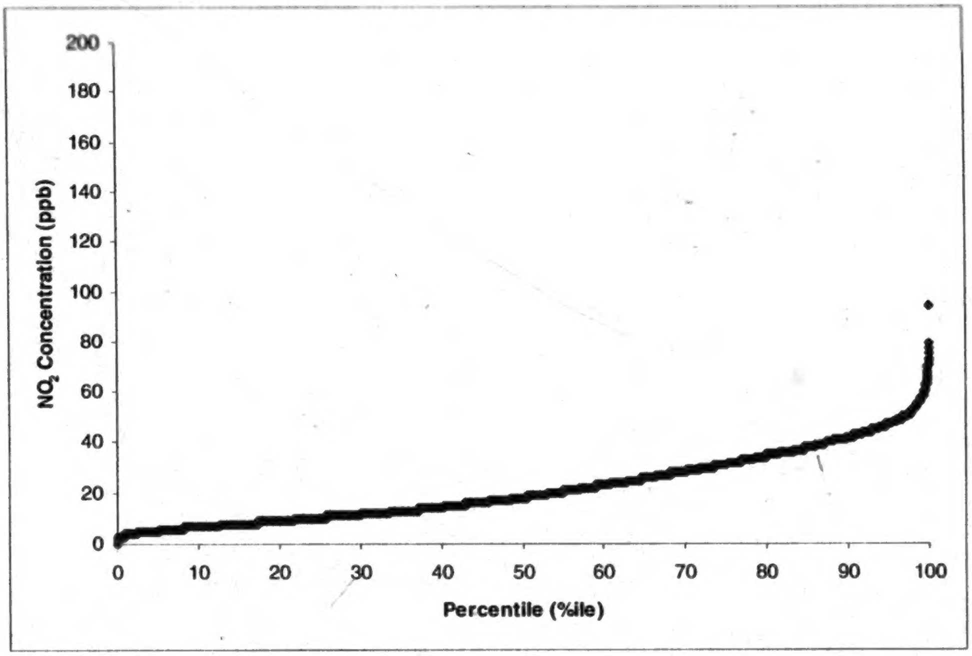

Figure 7-10: Cumulative frequency distribution for NO_2 - 2000 (Edmonton)

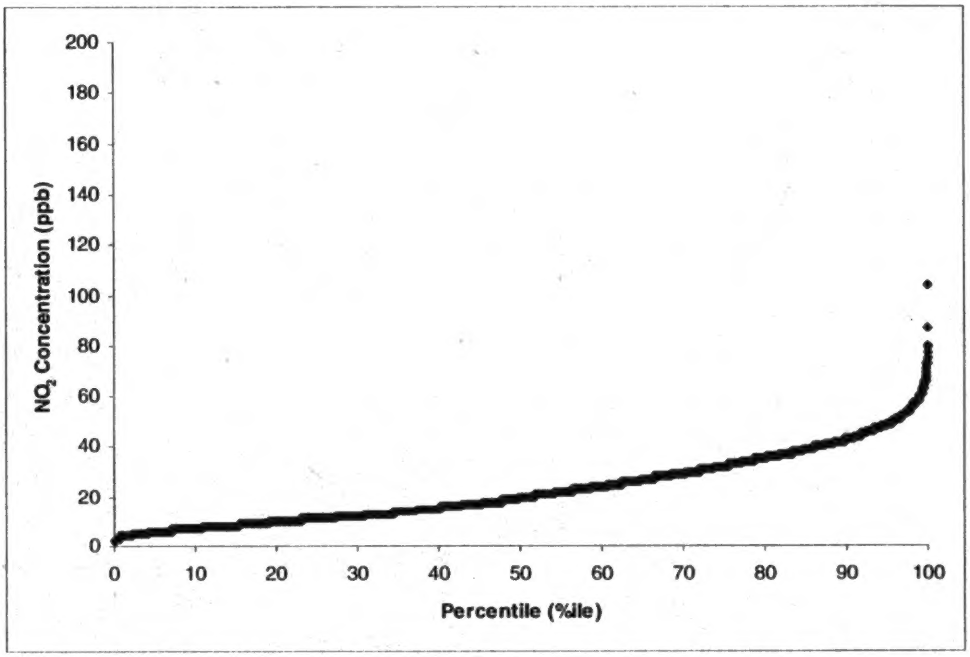

Figure 7-11: Cumulative frequency distribution for NO_2 - 2001 (Edmonton)

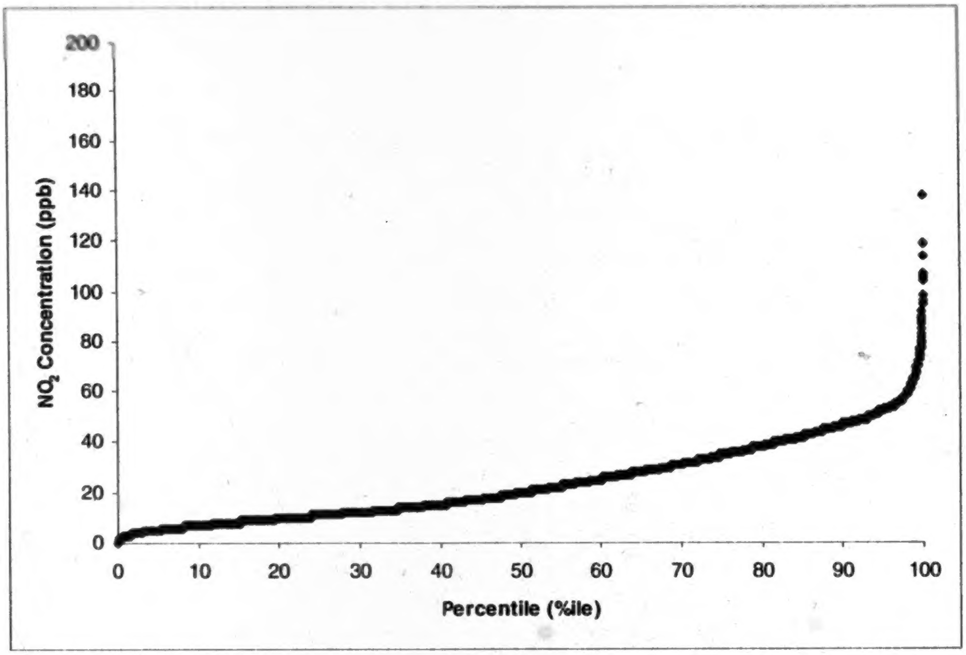

Figure 7-12: Cumulative frequency distribution for NO$_2$ - 2002 (Edmonton)

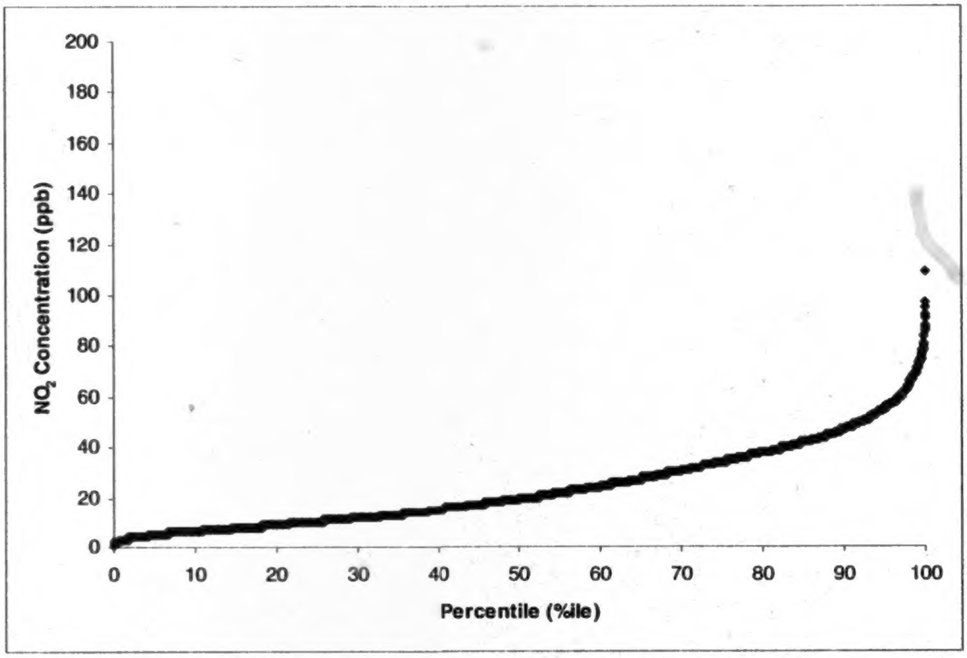

Figure 7-13: Cumulative frequency distribution for NO$_2$ - 2003 (Edmonton)

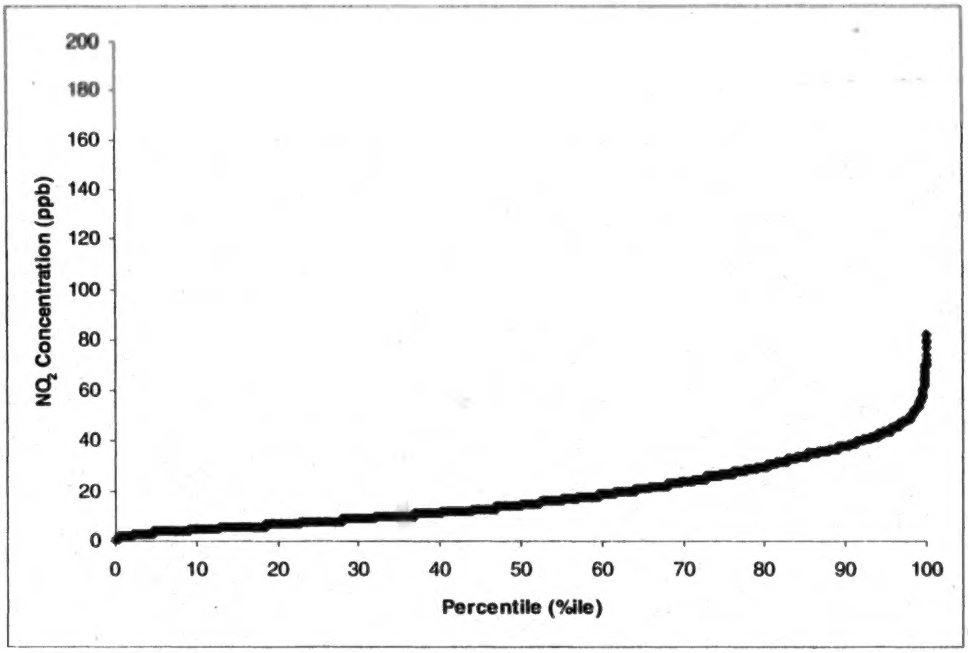

Figure 7-14: Cumulative frequency distribution for NO_2 - 2004 (Edmonton)

APPENDIX 7.5 Cumulative Frequency Distribution for CO - Edmonton Northwest (1998 – 2004)

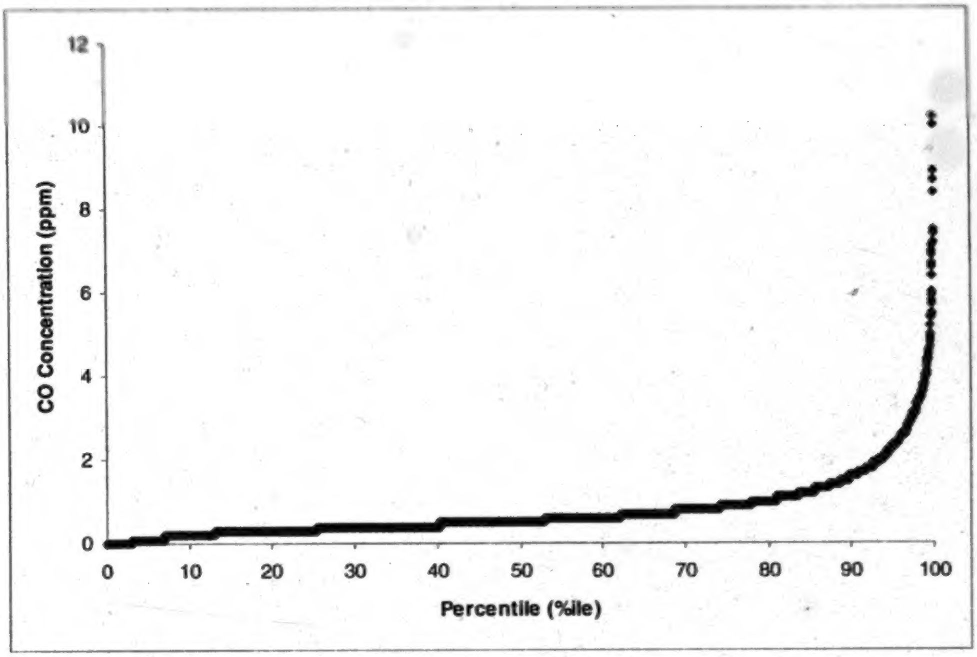

Figure 7-15: Cumulative frequency distribution for CO - 1998 (Edmonton)

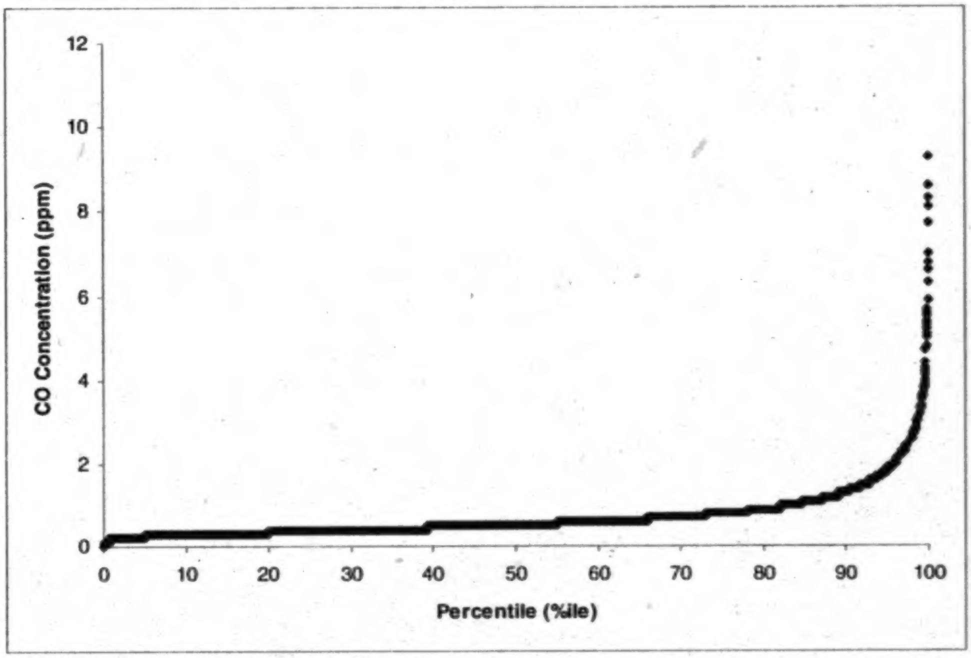

Figure 7-16: Cumulative frequency distribution for CO - 1999 (Edmonton)

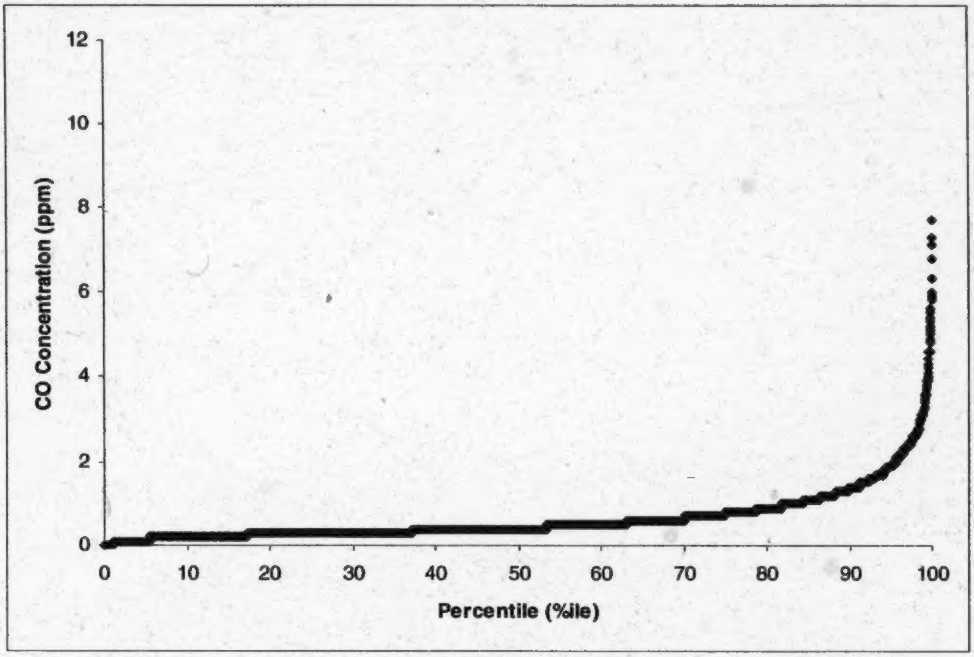

Figure 7-17: Cumulative frequency distribution for CO - 2000 (Edmonton)

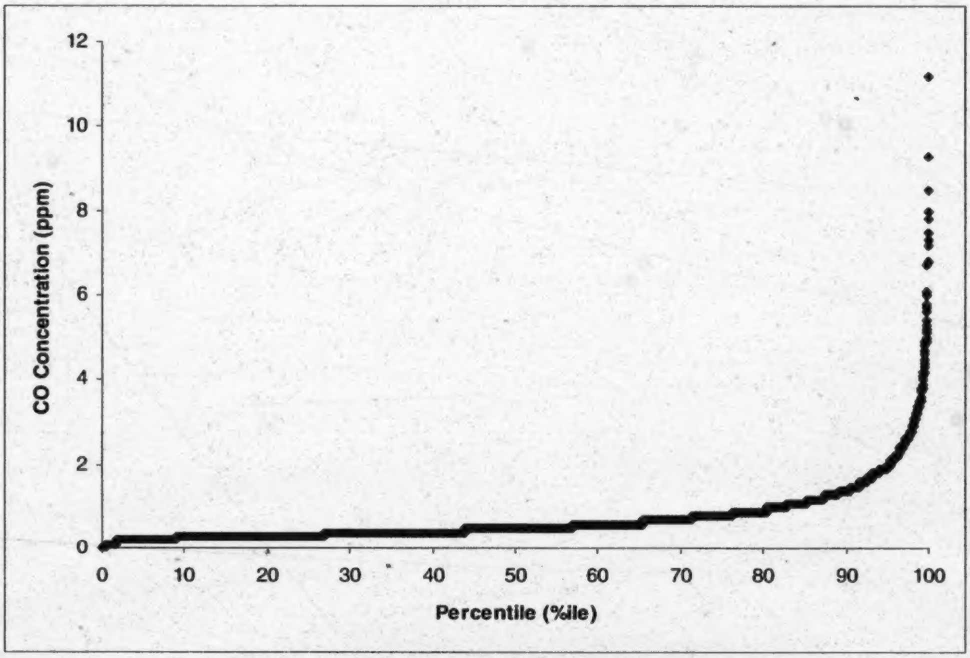

Figure 7-18: Cumulative frequency distribution for CO - 2001 (Edmonton)

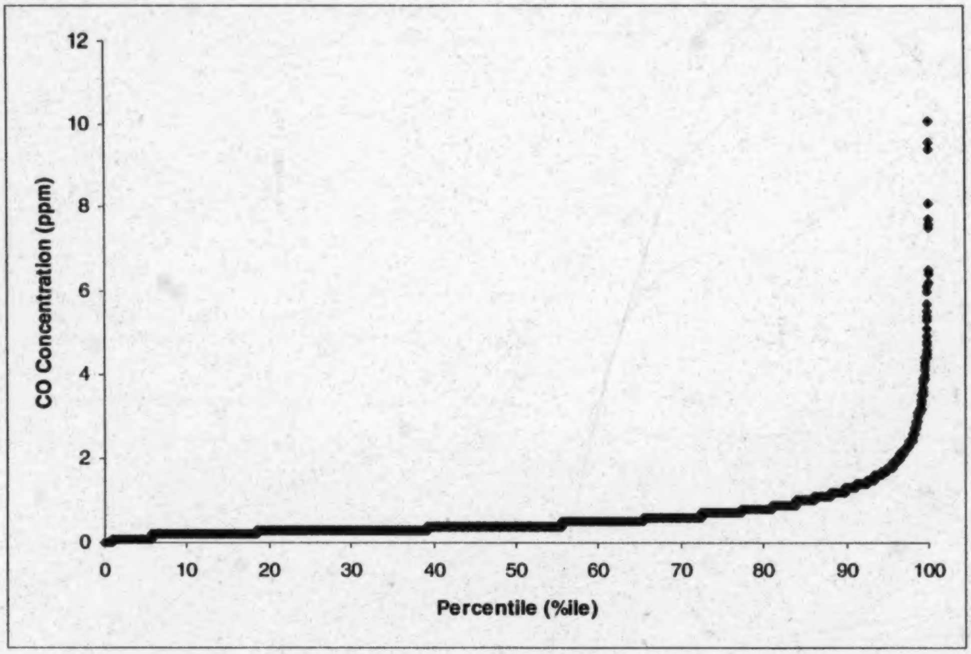

Figure 7-19: Cumulative frequency distribution for CO - 2002 (Edmonton)

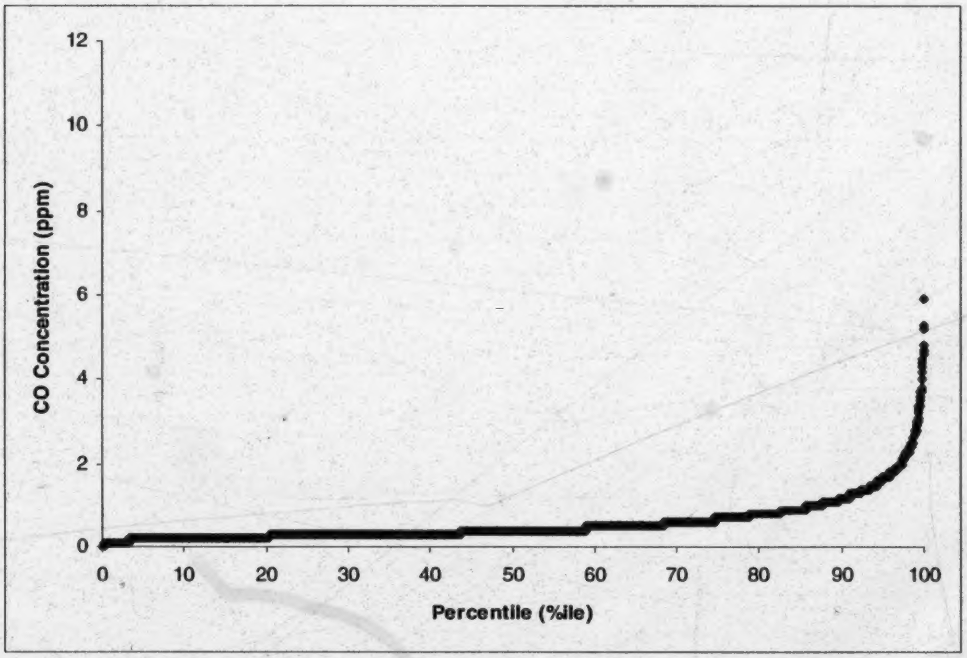

Figure 7-20: Cumulative frequency distribution for CO - 2003 (Edmonton)

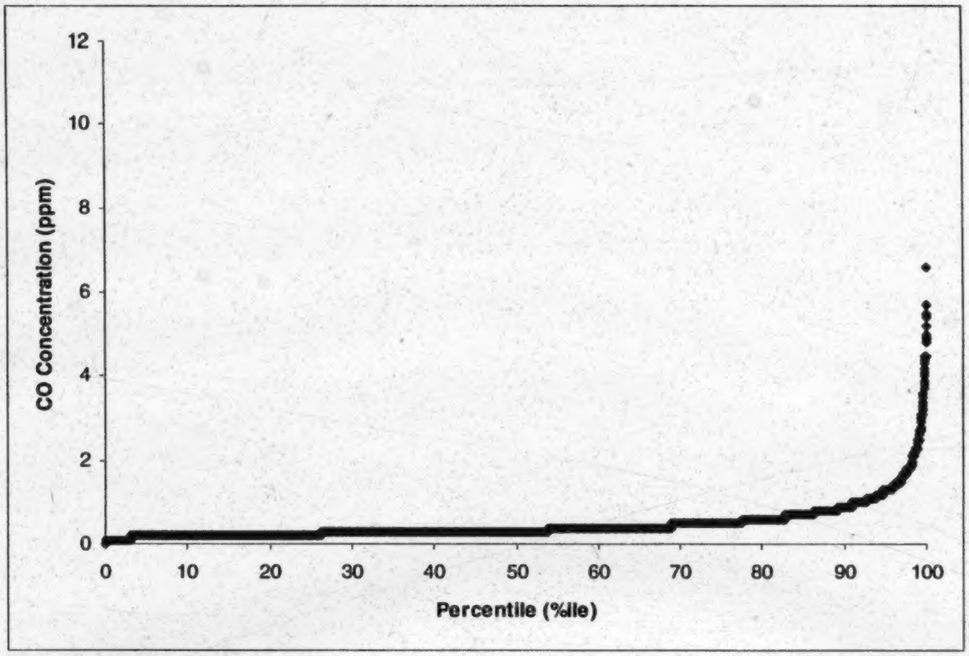

Figure 7-21: Cumulative frequency distribution for CO - 2004 (Edmonton)

APPENDIX 7.6 Cumulative Frequency Distribution for $PM_{2.5}$ - Edmonton Northwest (2000 – 2004)

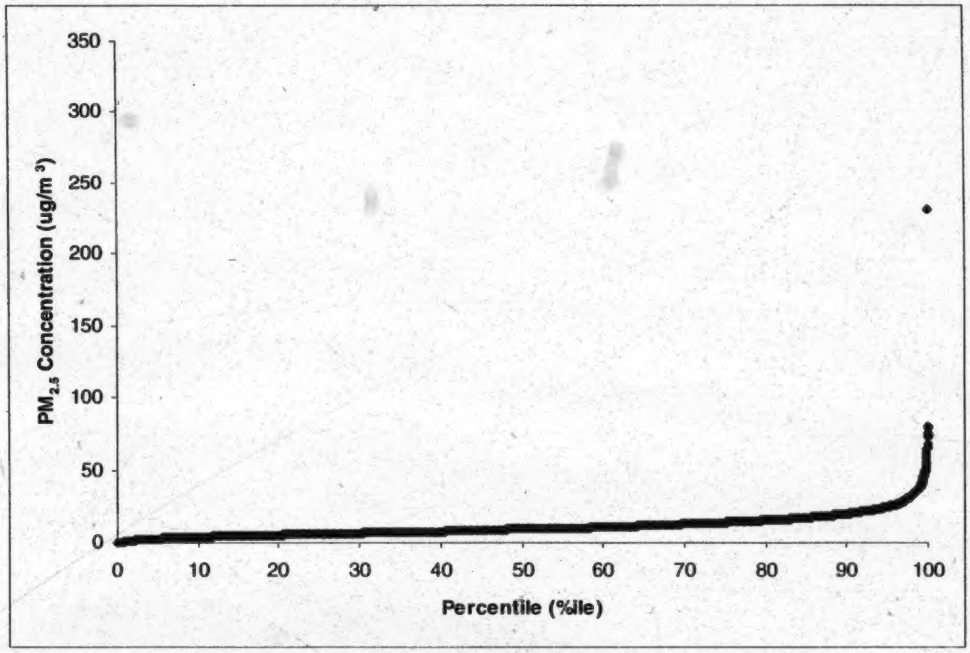

Figure 7-22: Cumulative frequency distribution for PM$_{2.5}$ - 2000 (Edmonton)

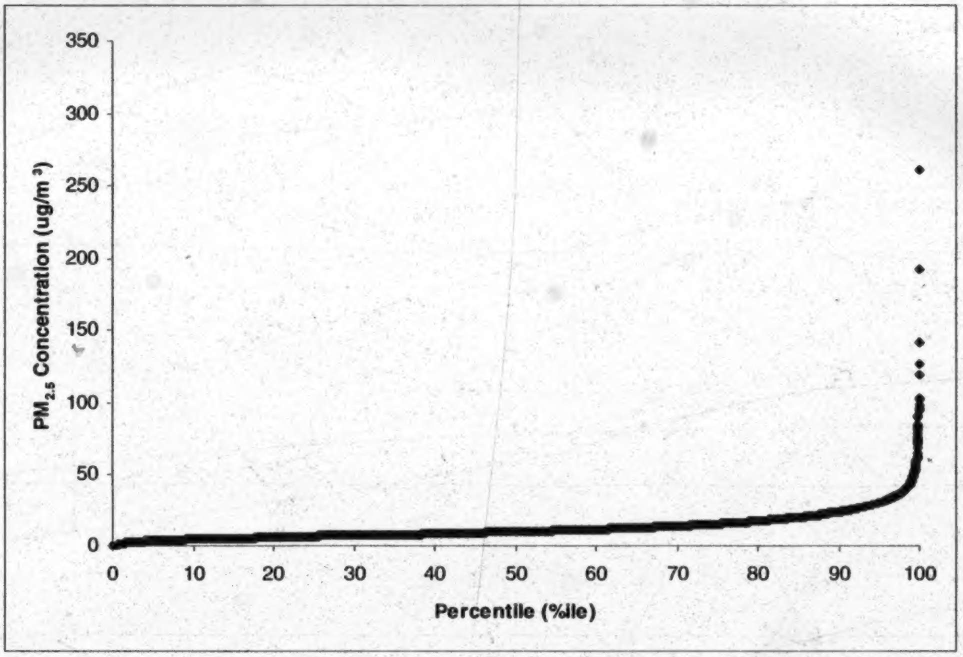

Figure 7-23: Cumulative frequency distribution for PM$_{2.5}$ - 2001 (Edmonton)

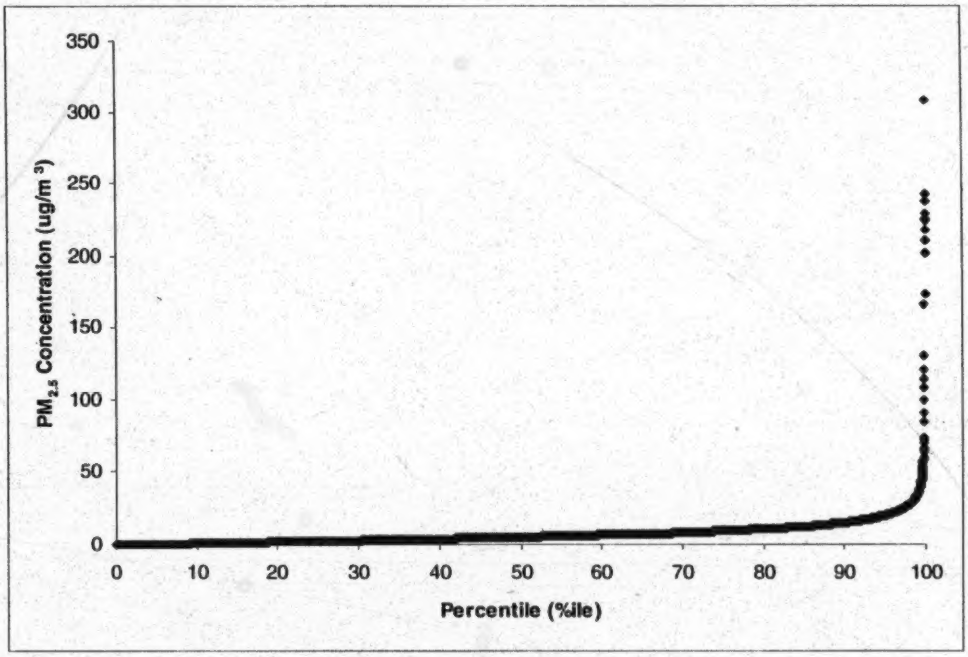

Figure 7-24: Cumulative frequency distribution for $PM_{2.5}$ - 2002 (Edmonton)

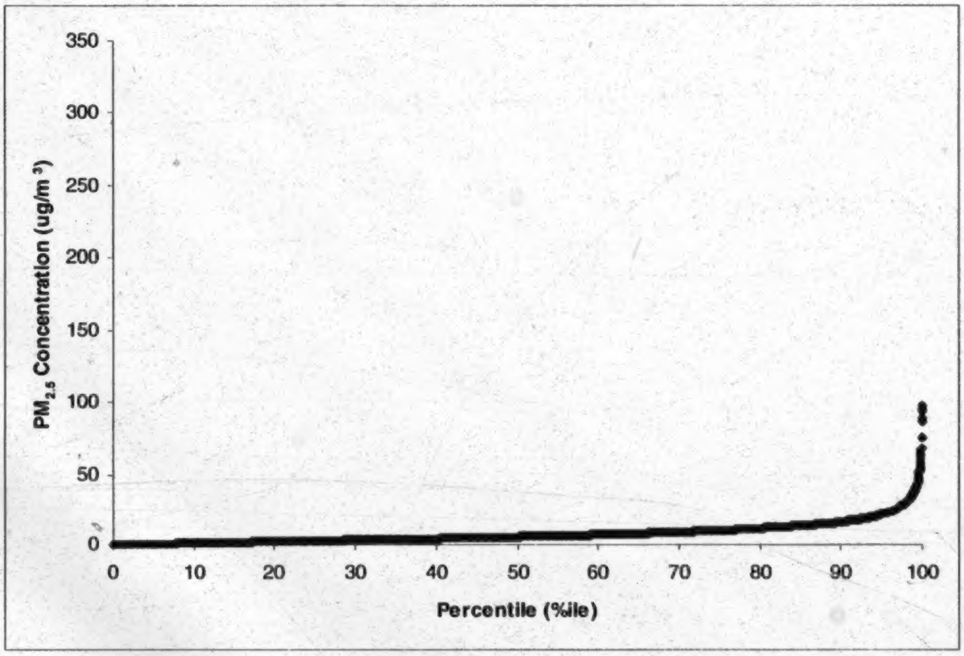

Figure 7-25: Cumulative frequency distribution for $PM_{2.5}$ - 2003 (Edmonton)

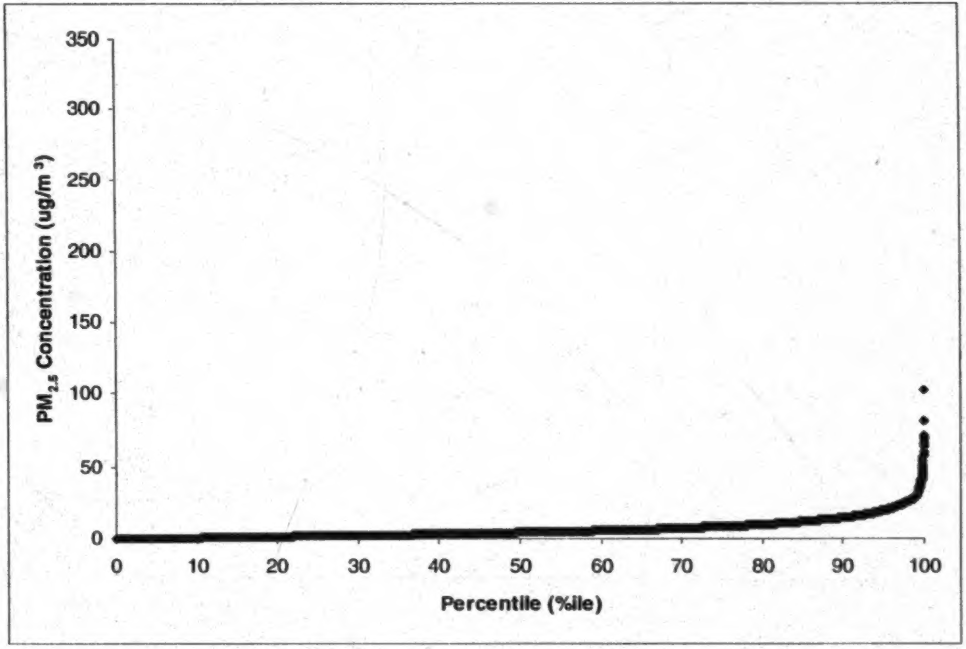

Figure 7-26: Cumulative frequency distribution for PM$_{2.5}$ - 2004 (Edmonton)

APPENDIX 7.7 Cumulative Frequency Distribution for Ozone - Fort McKay (2000 – 2004)

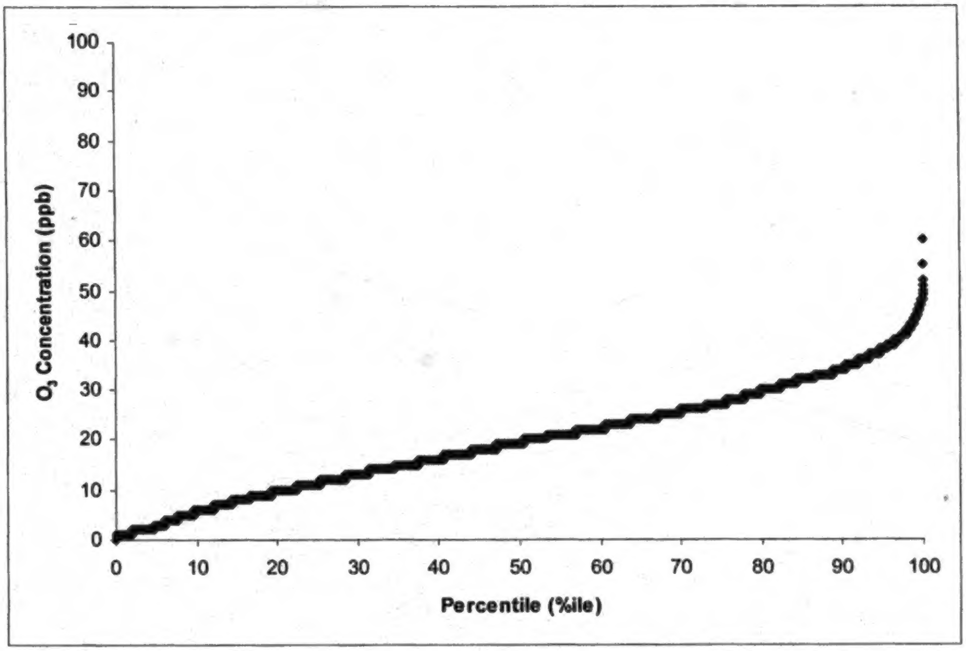

Figure 7-27: Cumulative frequency distribution for O_3 - 2000 (Fort McKay)

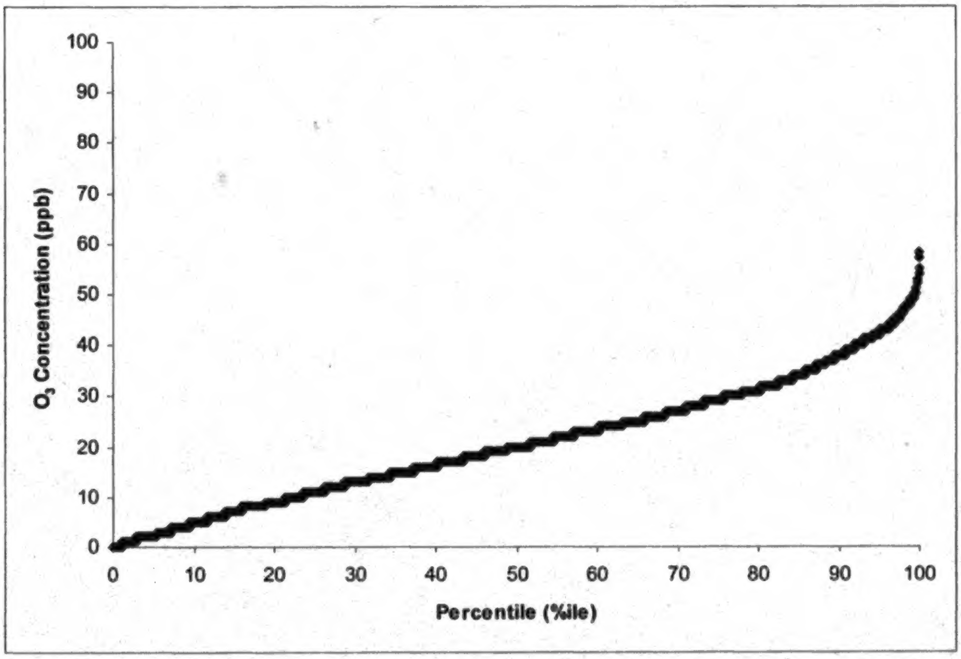

Figure 7-28: Cumulative frequency distribution for O_3 - 2001 (Fort McKay)

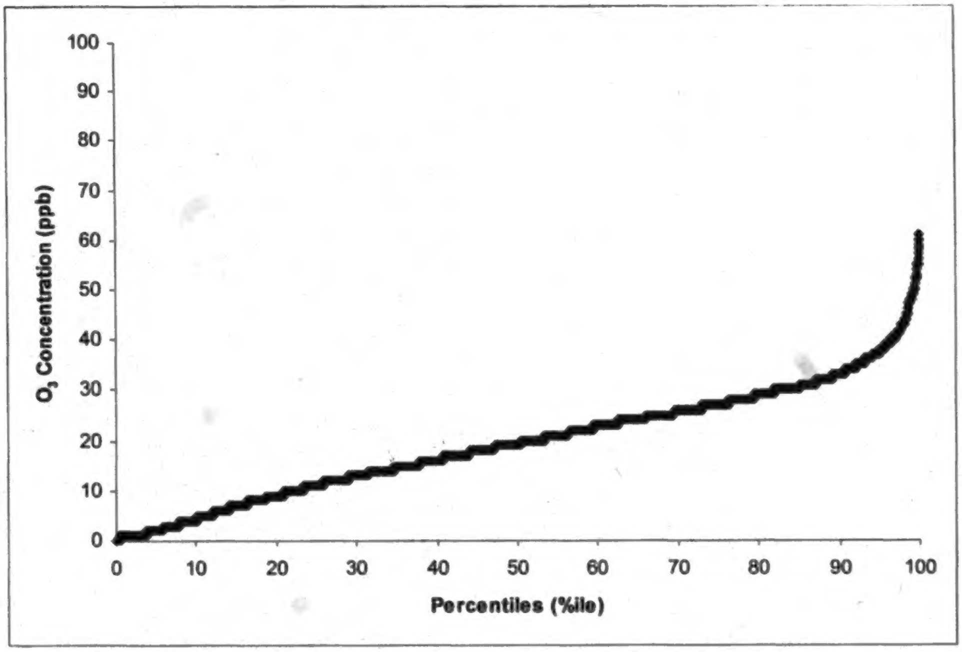

Figure 7-29: Cumulative frequency distribution for O_3 - 2002 (Fort McKay)

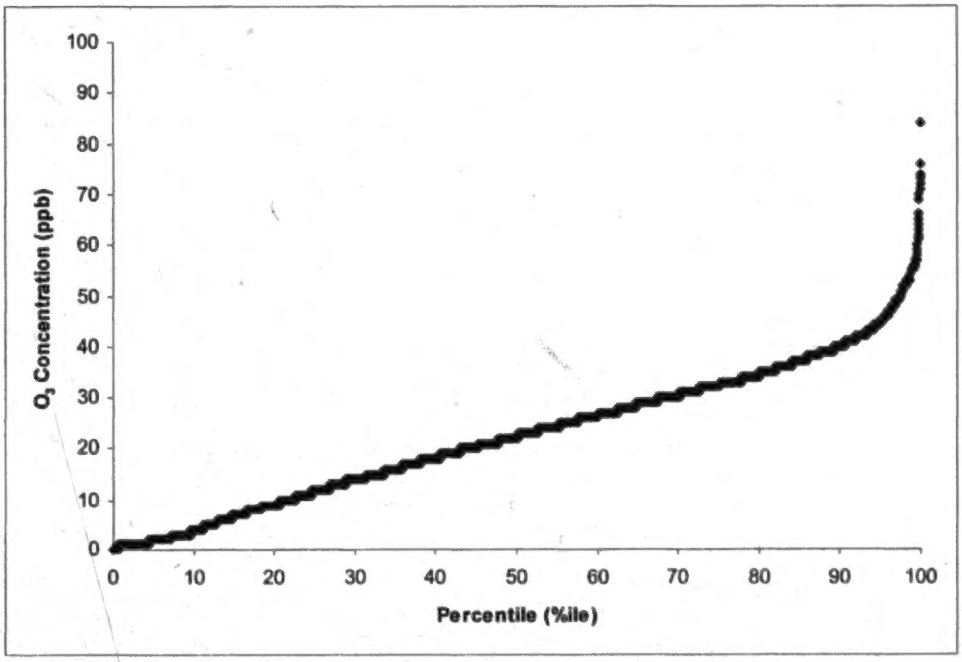

Figure 7-30: Cumulative frequency distribution for O_3 - 2003 (Fort McKay)

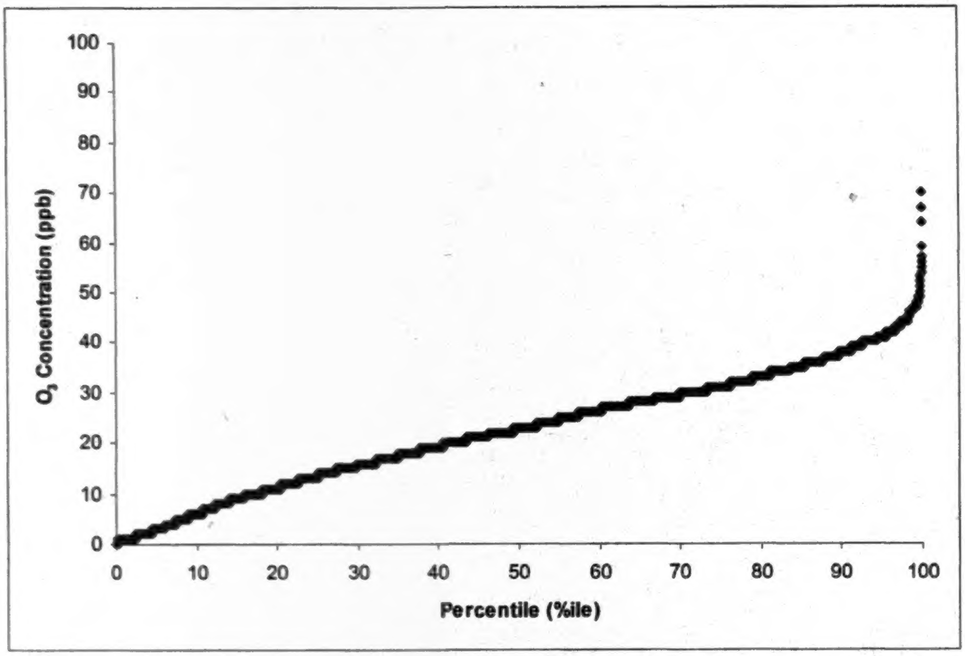

Figure 7-31: Cumulative frequency distribution for O_3 - 2004 (Fort McKay)

APPENDIX 7.8 Cumulative Frequency Distribution for NO_2 - Fort McKay (2000 – 2004)

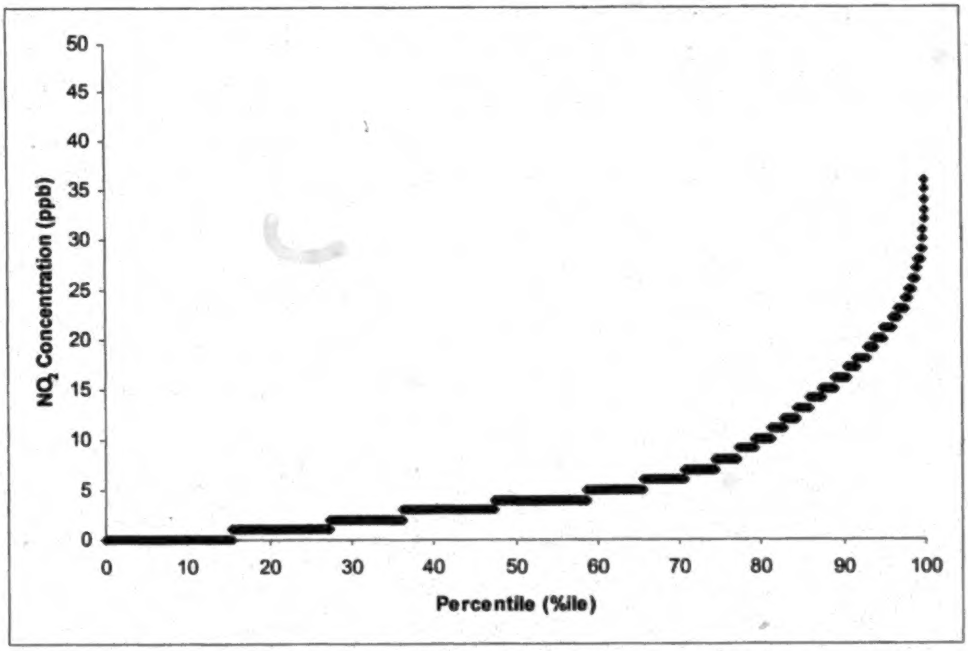

Figure 7-32: Cumulative frequency distribution for NO$_2$ - 2000 (Fort McKay)

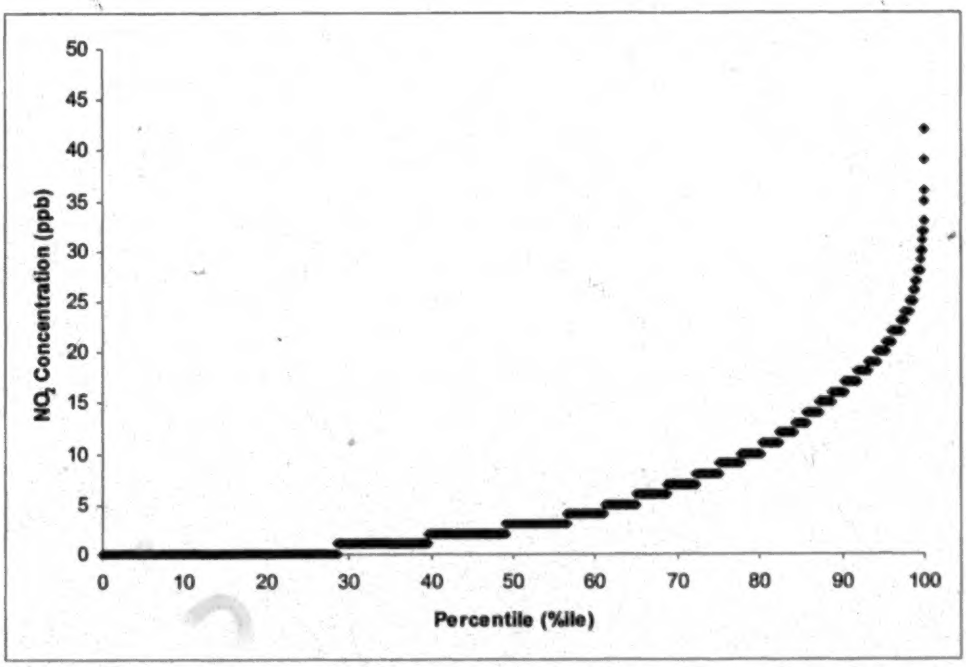

Figure 7-33: Cumulative frequency distribution for NO$_2$ - 2001 (Fort McKay)

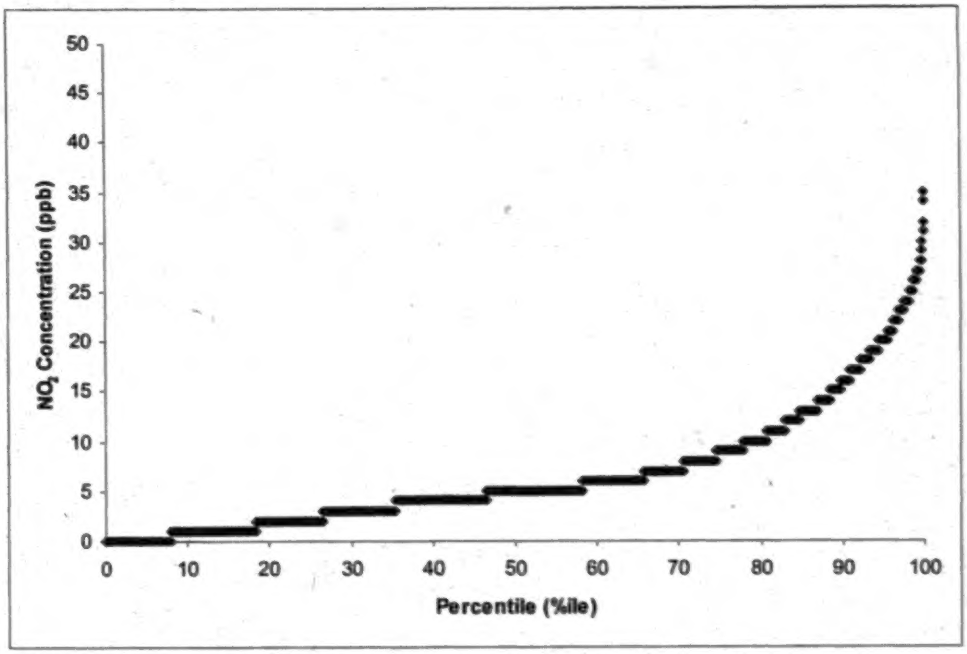

Figure 7-34: Cumulative frequency distribution for NO_2 - 2002 (Fort McKay)

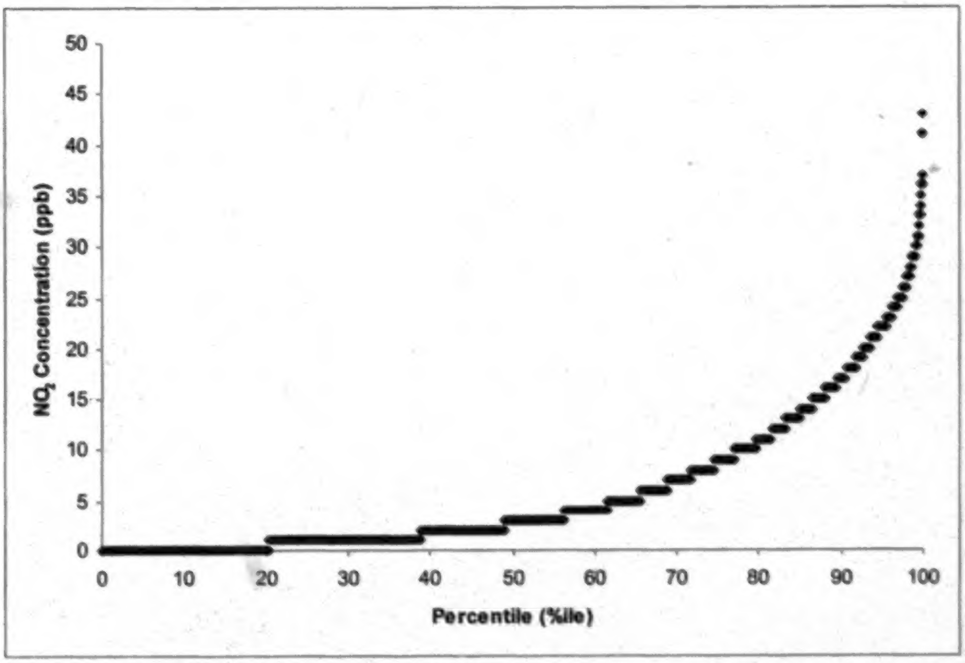

Figure 7-35: Cumulative frequency distribution for NO_2 - 2003 (Fort McKay)

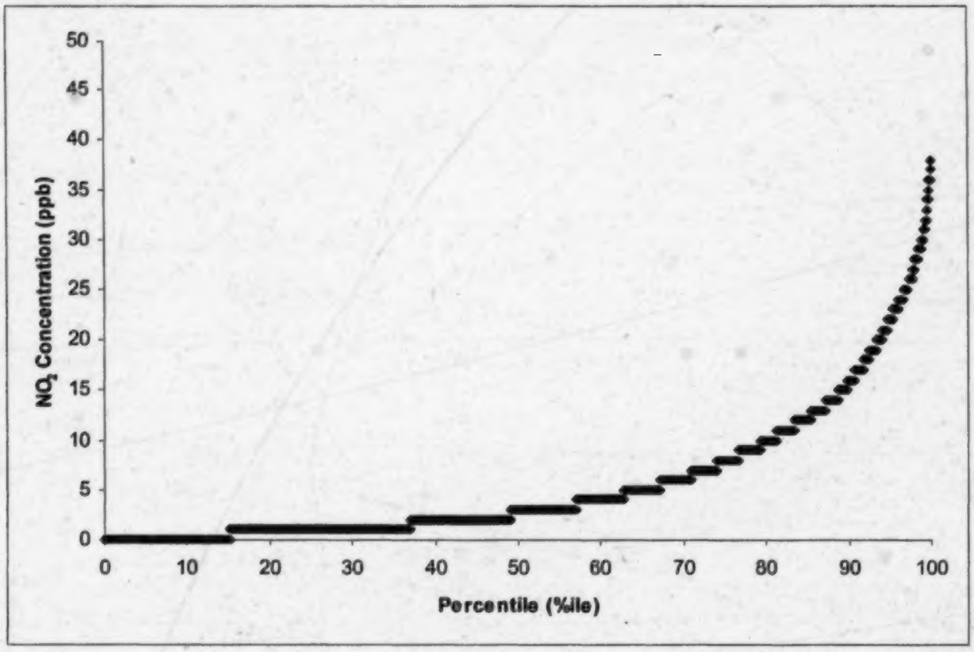

Figure 7-36: Cumulative frequency distribution for NO_2 - 2004 (Fort McKay)

APPENDIX 7.9 Cumulative Frequency Distribution for $PM_{2.5}$ - Fort McKay (2000 – 2004)

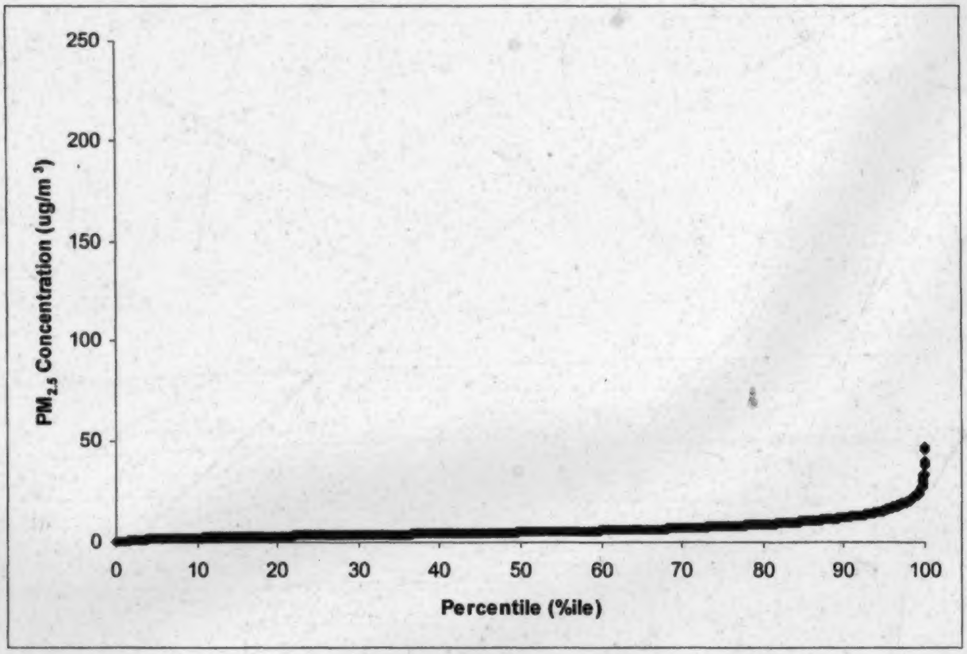

Figure 7-37: Cumulative frequency distribution for $PM_{2.5}$ – 2000 (Fort McKay)

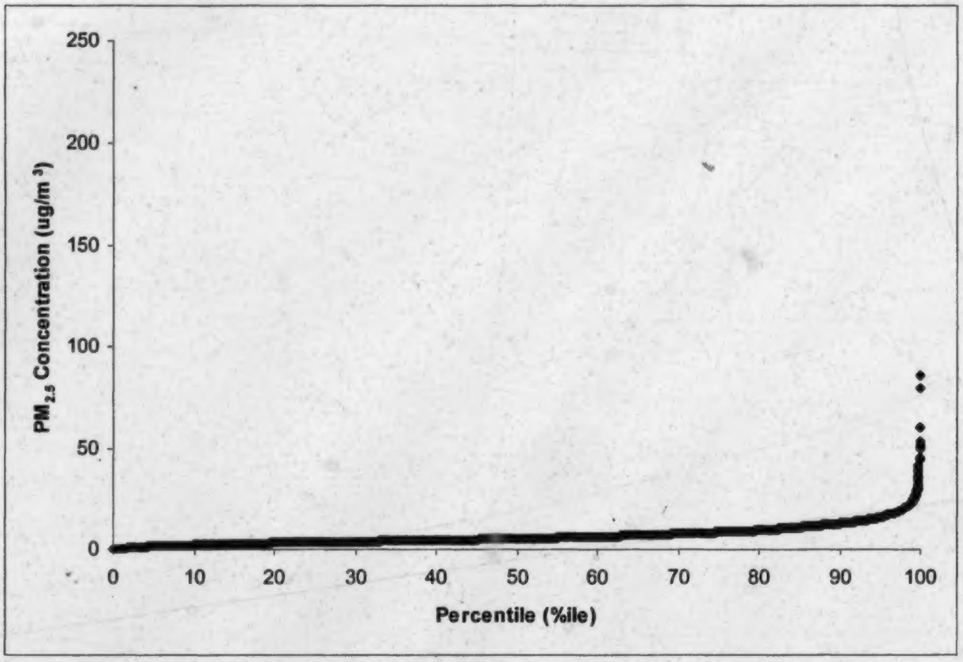

Figure 7-38: Cumulative frequency distribution for $PM_{2.5}$ – 2001 (Fort McKay)

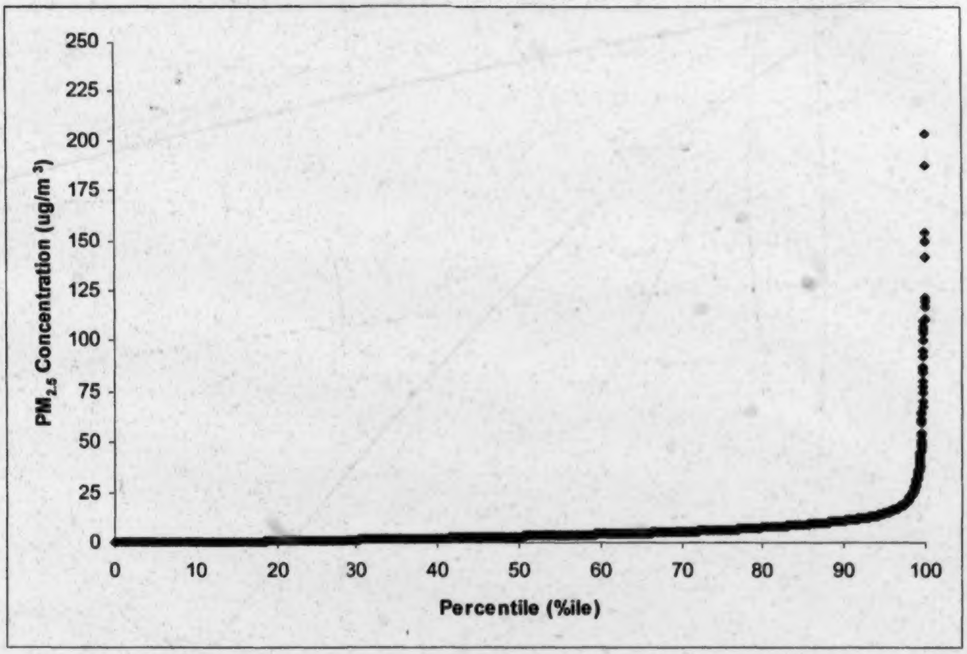

Figure 7-39: Cumulative frequency distribution for $PM_{2.5}$ – 2002 (Fort McKay)

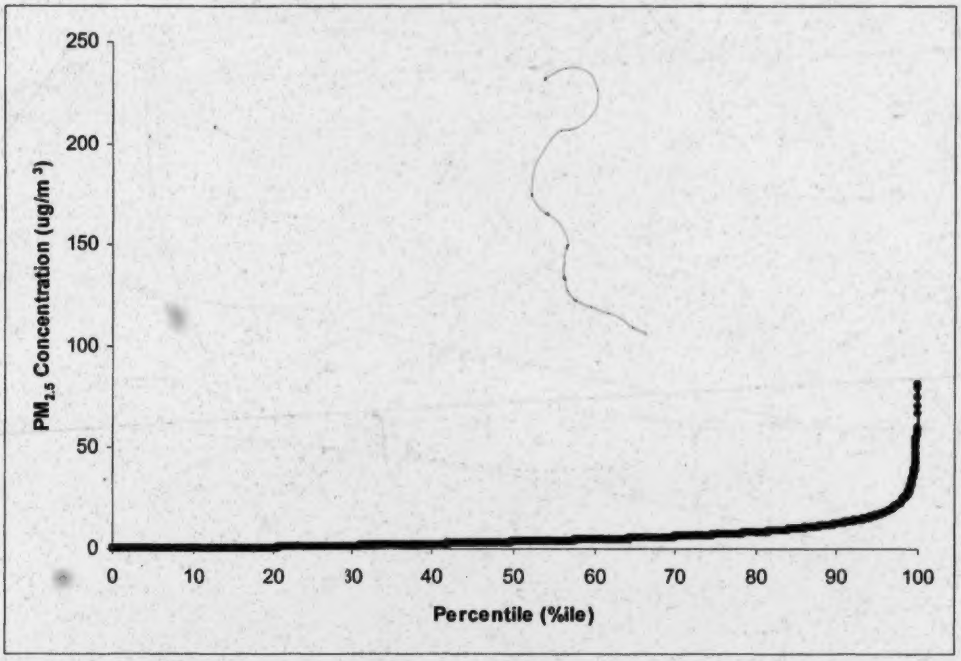

Figure 7-40: Cumulative frequency distribution for $PM_{2.5}$ – 2003 (Fort McKay)

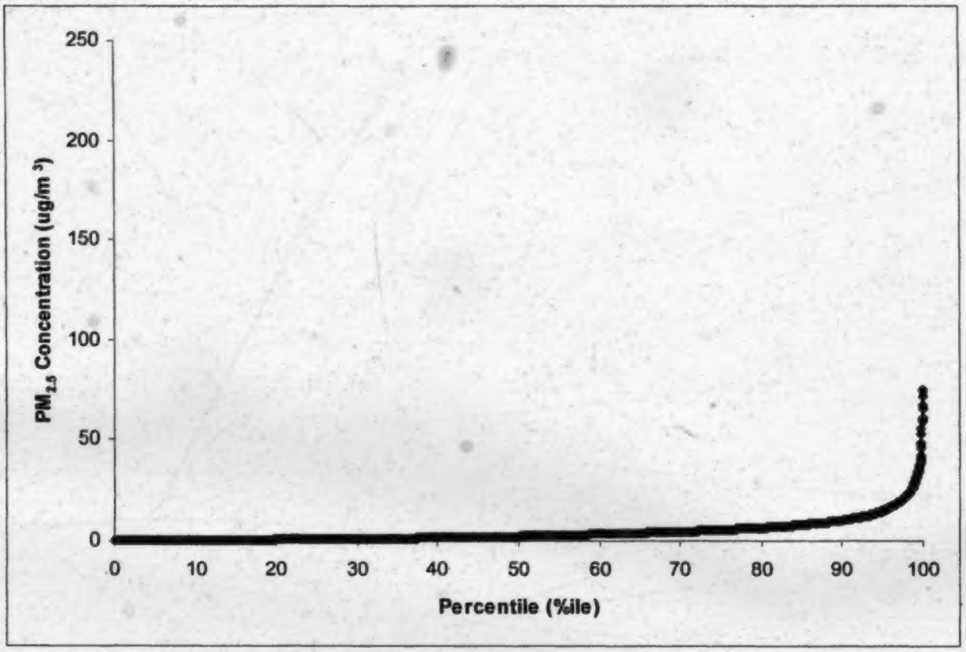

Figure 7-41: Cumulative frequency distribution for $PM_{2.5}$ – 2004 (Fort McKay)

APPENDIX 7.10 Cumulative Frequency Distribution for Total Hydrocarbons (THC) - Fort McKay (2000 – 2004)

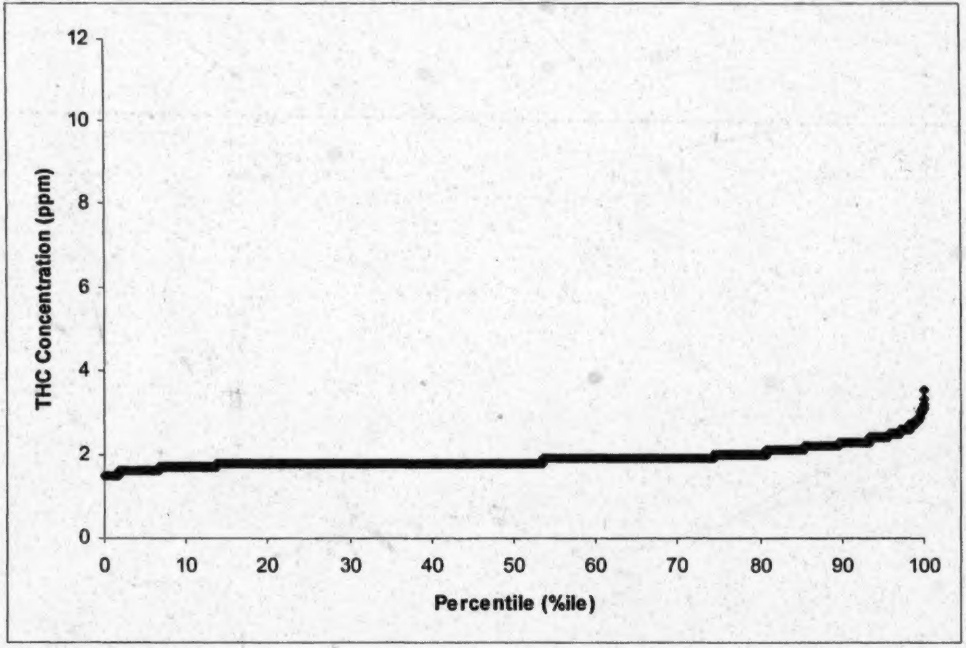

Figure 7-42: Cumulative frequency distribution for THC – 2000 (Fort McKay)

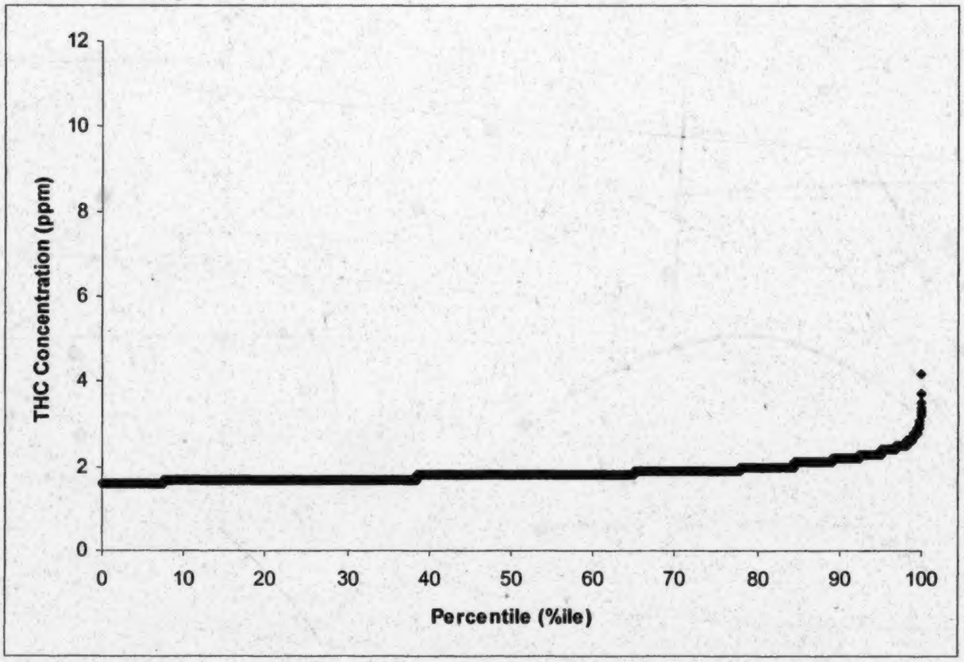

Figure 7-43: Cumulative frequency distribution for THC – 2001 (Fort McKay)

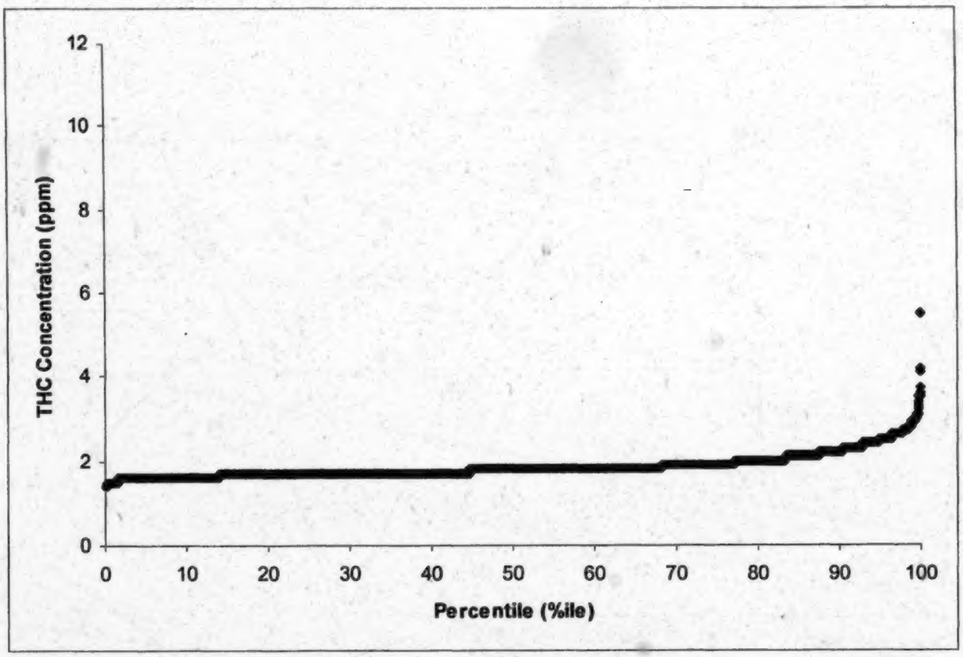

Figure 7-44: Cumulative frequency distribution for THC – 2002 (Fort McKay)

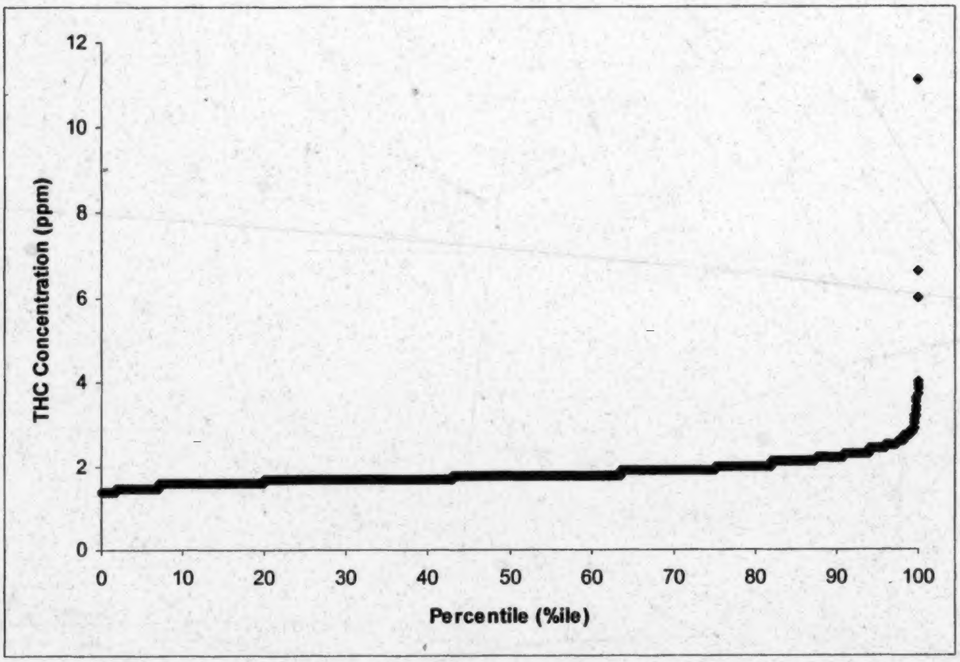

Figure 7-45: Cumulative frequency distribution for THC – 2003 (Fort McKay)

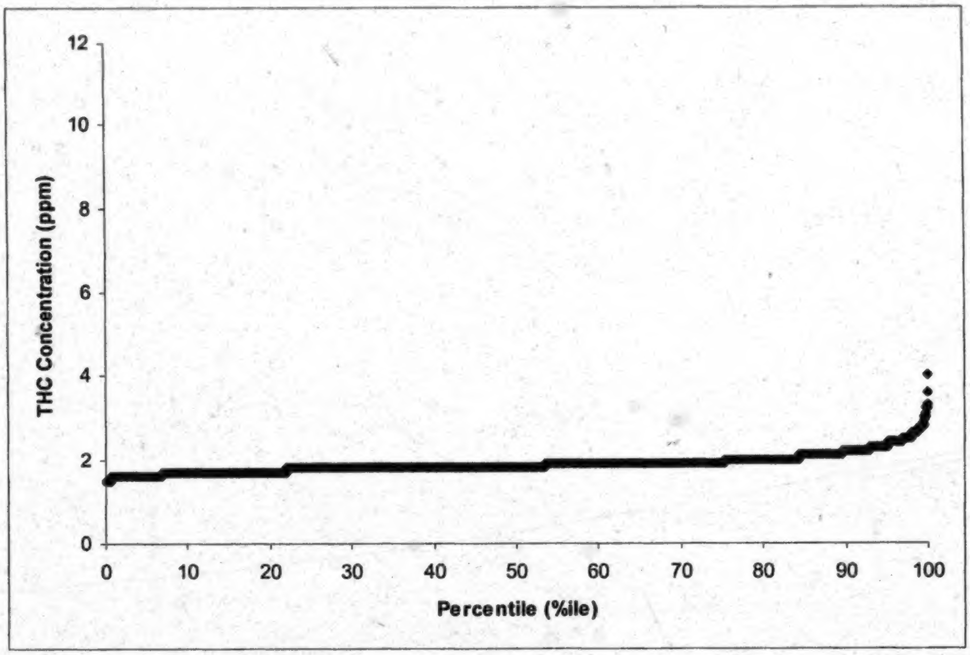

Figure 7-46: Cumulative frequency distribution for THC – 2004 (Fort McKay)

APPENDIX 7.11 Sample Calculation of Regression, t-test & ANOVA

A sample calculation of Regression statistics, the t-test and the ANOVA is provided in this section. The $PM_{2.5}$ concentration data for Edmonton Northwest station at the 50th percentile is used for the sample calculation.

Table 7-9: $PM_{2.5}$ data for Edmonton Northwest at 50th Percentile

Years	Concentration ($\mu g/m^3$) at 50th percentile
1999	10.0
2000	9.3
2001	9.8
2002	5.3
2003	5.5
2004	4.4

The $PM_{2.5}$ data for 50th percentile is plotted against time (years) in a scattered plot and the following regression model was obtained for the data set.

$\hat{y} = -1.25\,x + 11.77$

$\beta_{0(\text{Intercept})} = 11.77$

$\beta_{1(\text{Slope})} = -1.25$

Observations = 6

where '$\beta_{1(\text{Slope})}$' is used as 'b' in the formula

This slope was further tested for statistical significance by using the t-test and the ANOVA at a significance level of $\alpha = 0.05$.

Table 7-10: Observed, Estimated and Residual values for the Least-Square Regression

x	$(x_i - x_{bar})^2$	Observed values 'y_i'	Predicted values '$\hat{y}$'	Residual $e = (y_i - \hat{y})$
1	6.25	10.0	10.52	-0.52
2	2.25	9.3	9.26	0.04
3	0.25	9.8	8.01	1.79
4	0.25	5.3	6.76	-1.46
5	2.25	5.5	5.50	0.00
6	6.25	4.4	4.25	0.15

where SSX is the Standard Error of the Estimates $SSX = \sum \left(X - \overline{X}\right)^2$

$SSX = 17.5$

and

$$SST_{\text{(Total variation)}} = \sum_{i=1}^{n}\left(yi - \bar{y}\right)^2$$

$$SSE_{\text{(Unexplained variation)}} = \sum_{i=1}^{n}\left(yi - \hat{y}\right)^2$$

$$SSR_{\text{(Explained variation)}} = \sum_{i=1}^{n}\left(\hat{y} - \bar{y}\right)^2$$

Table 7-11: Calculation of SST, SSE and SSR

SST	SSE	SSR
6.85	0.27	9.83
3.67	0.00	3.54
5.84	3.20	0.39
4.34	2.12	0.39
3.55	0.00	3.54
8.90	0.02	9.84
SST = 33.15	SSE = 5.62	SSR = 27.53

The degrees of freedom for the SST, SSE, and SSR are identified and the MSE and MSR are calculated as shown in Table 7.12

Where $MSE_{\text{(Mean Square Error)}} = \dfrac{SSE}{(n-2)}$

$MSR_{\text{(Mean Square Regression)}} = \dfrac{SSR}{1}$

Table 7-12: SST, SSE and SSR, degrees of Freedom and MSE and MSR

SST = 33.15	SSE = 5.62	SSR = 27.53
df = 5	df = 4	df = 1
MST = 6.63	MSE = 1.40	MSR = 27.53

a) t $_{\text{(statistics)}}$

$$t_{\text{(statistics)}} = \frac{\text{Statistic hypothesized value}}{\text{Estimated standard error of the statistic}}$$

Or

$$t_{(n-2)} = \frac{b - b_0}{S_b}$$

where $b_0 = 0$ and b = slope

$$S_b = \frac{S_e}{\sqrt{SSX}}$$

Where 'S_b' is the standard error of the regression co-efficient 'b'

$$S_e = \sqrt{\frac{SSE}{(n-2)}}$$

Where 'S_e' is the standard error of estimate

$$S_e = \sqrt{\frac{SSE}{df_{(SSE)}}} = \sqrt{\frac{5.62}{4}} = 1.18$$

$Se = 1.18$

$$Sb = \frac{Se}{\sqrt{SSX}} = \frac{1.18}{\sqrt{17.5}} = 0.283$$

$S_b = 0.283$

$$t_{(n-2)} = \frac{b - b_0}{S_b}$$

$$t_{\text{(statistics)}} = \frac{(-1.25 - 0)}{0.283} = -4.43$$

so $t_{\text{(calculated)}} = 4.43$

$t_{\text{(tabulated)}} = 2.77$

so $t_{\text{(calculated)}} > t_{\text{(tabulated)}}$

Reject the Hypothesis that slope = 0, indicating that a decreasing trend exists

b) ANOVA ($F_{\text{(Statistics)}}$)

$$F_{\text{(Statistics)}} = F_{(1,\, n-2)} = \frac{MSR}{MSE}$$

$$F_{\text{(Statistics)}} = \frac{27.53}{1.40} = 19.6$$

$F_{\text{(Statistics)}} = 19.6$

$F_{\text{(tabulated)}} = 7.71$

Thus $F_{\text{(Statistics)}} > F_{\text{(tabulated)}}$

Reject the Hypothesis that slope = 0, thus a decreasing trend exists

APPENDIX 7.12 Concentration data at different percentiles of Concentration based bench marks for O_3, NO_2, CO and $PM_{2.5}$ – Edmonton Northwest station

Table 7-13: Concentration of O_3 at different percentiles (1997 – 2004) for Edmonton Northwest station

Years	O_3 Concentration (ppb)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	15	23	32	41	48	57
1998	17	25	34	43	50	57
1999	16	22	29	37	43	49
2000	15	21	29	36	42	48
2001	16	24	33	40	45	50
2002	18	26	33	38	44	51
2003	21	28	36	43	49	56
2004	18	24	32	39	45	50

Table 7-14: Concentration of NO_2 at different percentiles (1997 – 2004) for Edmonton Northwest station

Years	NO_2 Concentration (ppb)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	22	30	40	51	60	72
1998	20	27	36	45	52	59
1999	18	25	34	41	47	53
2000	18	26	35	42	47	53
2001	20	27	35	43	49	55
2002	20	28	38	47	52	59
2003	20	27	38	47	55	65
2004	14	21	30	38	44	50

Table 7-15: Concentration of CO at different percentiles (1997 – 2004) for Edmonton Northwest station

Years	CO Concentration (ppm)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	0.4	0.6	0.9	1.5	2.2	3.4
1998	0.5	0.7	1	1.6	2.3	3.3
1999	0.5	0.6	0.9	1.3	1.8	2.7
2000	0.4	0.6	1	1.4	1.9	2.7
2001	0.5	0.6	0.9	1.4	2	2.8
2002	0.4	0.5	0.8	1.3	1.8	2.5
2003	0.4	0.5	0.8	1.2	1.6	2.3
2004	0.3	0.4	0.6	0.9	1.3	1.9

Table 7-16: Concentration of $PM_{2.5}$ at different percentiles (1999 – 2004) Edmonton Northwest station

Years	$PM_{2.5}$ Concentration ($\mu g/m^3$)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	10.0	12.8	16.8	21.5	26.3	32.5
2000	9.3	11.8	15.5	20.0	24.8	32.8
2001	9.8	12.3	17.0	23.8	30.3	39.3
2002	5.3	7.5	10.8	15.0	20.0	28.0
2003	5.5	7.8	11.6	16.0	21.7	30.4
2004	4.4	6.5	10.0	14.6	19.8	26.1

APPENDIX 7.13 Concentration data at different percentiles of Concentration based bench marks for O_3, NO_2, $PM_{2.5}$ and THC – Fort McKay

Table 7-17: Concentration of O_3 at different percentiles (1999 – 2004) for Fort McKay

Years	O_3 Concentration (ppb)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	20	25	30	37	42	46
2000	19	24	30	34	38	42
2001	20	25	31	38	42	46
2002	19	24	29	33	37	43
2003	22	29	34	40	45	52
2004	23	28	33	38	41	44

Table 7-18: Concentration of NO_2 at different percentiles (1999 – 2004) for Fort McKay

Years	NO_2 Concentration (ppb)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	1	3	7	12	16	19
2000	4	5	10	16	21	24
2001	3	6	10	16	20	24
2002	5	6	10	16	20	24
2003	3	5	11	17	22	26
2004	3	5	10	16	22	27

Table 7-19: Concentration of $PM_{2.5}$ at different percentiles (1999 – 2004) for Fort McKay

Years	$PM_{2.5}$ Concentration ($\mu g/m^3$)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	4.8	6.0	8.2	10.9	13.9	18.0
2000	4.9	6.3	8.8	12.3	15.7	20.5
2001	5.3	6.9	9.4	12.6	15.9	20.6
2002	3.0	4.6	7.5	11.0	14.8	22.0
2003	3.1	4.9	8.0	12.1	16.6	23.9
2004	2.2	3.8	6.5	10.1	14.8	22.6

Table 7-20: Concentration of THC at different percentiles (1999 – 2004) for Fort McKay

Years	THC Concentration (ppm)					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	1.9	2.0	2.1	2.3	2.4	2.6
2000	1.8	1.9	2.0	2.3	2.4	2.6
2001	1.8	1.8	2.0	2.2	2.3	2.5
2002	1.8	1.8	2.0	2.2	2.5	2.7
2003	1.8	1.9	2.0	2.2	2.4	2.6
2004	1.8	1.9	2.0	2.2	2.3	2.6

APPENDIX 7.14 Frequency data at different percentiles of Frequency based bench marks for O_3, NO_2, CO and $PM_{2.5}$ – Edmonton Northwest station

Table 7-21: Frequency – number of hours exceeded – at different percentiles for O_3 (1997 – 2004) - Edmonton Northwest station

Years	O_3 Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	4278	3000	1657	805	418	161
1998	4535	3311	1973	1005	499	172
1999	4446	2797	1341	508	191	22
2000	4170	2589	1198	463	172	22
2001	4341	3080	1793	761	227	40
2002	4716	3432	1813	565	229	82
2003	5106	3903	2339	1047	473	125
2004	4803	3218	1682	691	214	39

Table 7-22: Frequency – number of hours exceeded – at different percentiles for NO_2 (1997 – 2004) - Edmonton Northwest station

Years	NO_2 Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	4009	2794	1625	809	390	163
1998	3696	2360	1176	439	133	24
1999	3456	2139	937	241	52	3
2000	3582	2317	1024	202	43	7
2001	3795	2444	1107	294	75	14
2002	3754	2617	1446	467	148	47
2003	3807	2620	1439	606	259	71
2004	2786	1712	678	139	34	7

Table 7-23: Frequency – number of hours exceeded – at different percentiles for CO (1997 – 2004) - Edmonton Northwest station

Years	CO Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1997	3875	2625	1683	827	422	169
1998	5173	3284	1907	886	450	150
1999	5304	2960	1577	631	287	72
2000	4067	2613	1587	676	302	73
2001	4840	2974	1686	729	320	92
2002	3862	2385	1389	571	239	69
2003	3573	2218	1252	506	186	42
2004	2708	1501	794	278	117	36

Table 7-24: Frequency – number of hours exceeded – at different percentiles for $PM_{2.5}$ (1999 – 2004) - Edmonton Northwest station

Years	$PM_{2.5}$ Frequency – number of hours exceeded					
	(50%)	**(65%)**	**(80%)**	**(90%)**	**(95%)**	**(98%)**
1999	4336	2977	1728	859	429	169
2000	3914	2654	1429	718	354	173
2001	4019	2812	1765	1071	654	333
2002	1942	1208	663	363	213	113
2003	2167	1413	763	442	254	137
2004	1728	1160	632	348	168	66

APPENDIX 7.15 Frequency data at different percentiles of Frequency based bench marks for O_3, NO_2, $PM_{2.5}$ and THC – Fort McKay

Table 7-25: Frequency – number of hours exceeded – at different percentiles for O_3 (1999 – 2004) – Fort McKay

Years	O_3 Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	4129	2678	1579	765	350	136
2000	3883	2495	1476	452	130	39
2001	4002	2835	1826	871	402	165
2002	3874	2534	1243	412	180	107
2003	4537	3518	2477	1168	565	337
2004	4725	3550	2225	857	273	92

Table 7-26: Frequency – number of hours exceeded – at different percentiles for NO_2 (1999 – 2004) - Fort McKay

Years	NO_2 Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	3565	2499	1435	691	329	151
2000	5992	4341	2108	1289	788	503
2001	4958	3574	2280	1296	798	463
2002	6734	5340	2424	1261	750	460
2003	5003	3570	2300	1365	857	604
2004	5095	3467	2109	1172	742	537

Table 7-27: Frequency – number of hours exceeded – at different percentiles for $PM_{2.5}$ (1999 – 2004) - Fort McKay

Years	$PM_{2.5}$ Frequency – number of hours exceeded					
	(50%)	(65%)	(80%)	(90%)	(95%)	(98%)
1999	4174	2969	1705	842	415	168
2000	4387	3214	1976	1138	603	299
2001	4725	3632	2238	1278	649	279
2002	2803	2163	1446	841	467	259
2003	3036	2414	1604	1042	631	347
2004	2411	1896	1238	762	488	299

Table 7-28: Frequency – number of hours exceeded – at different percentiles for THC (1999 – 2004) - Fort McKay

	THC Frequency – number of hours exceeded					
Years	**(50%)**	**(65%)**	**(80%)**	**(90%)**	**(95%)**	**(98%)**
1999	3203	2198	1488	550	353	122
2000	2086	1565	1187	540	351	136
2001	1831	1276	890	410	251	88
2002	1897	1372	1033	591	417	191
2003	2051	1479	1034	490	324	141
2004	2047	1300	857	401	264	102

APPENDIX 7.16 Frequency-based air quality trends for O_3, NO_2, CO and $PM_{2.5}$ – Edmonton Northwest station

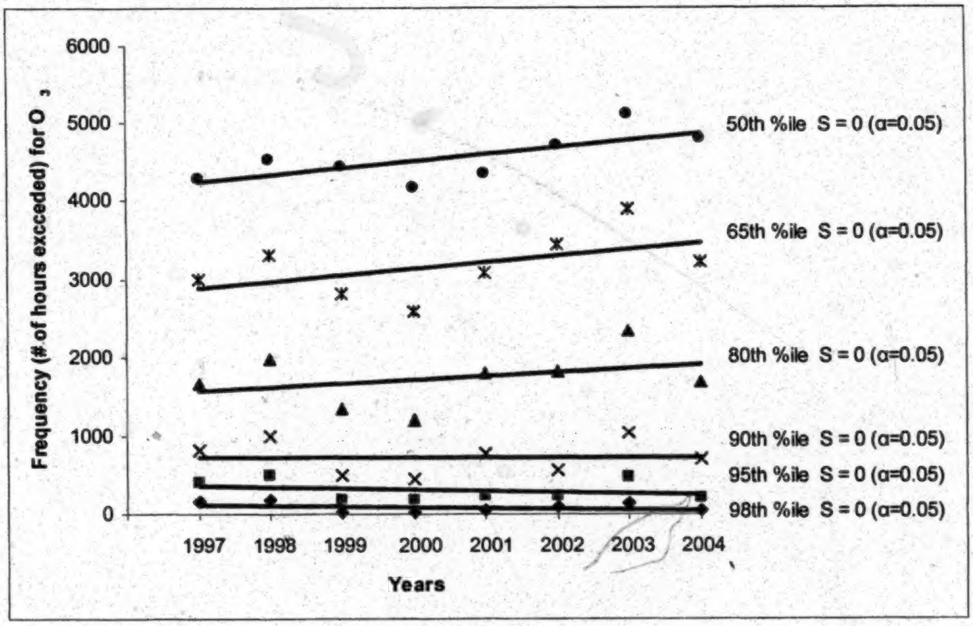

Figure 7-47: Edmonton Northwest air quality frequency trends for O_3

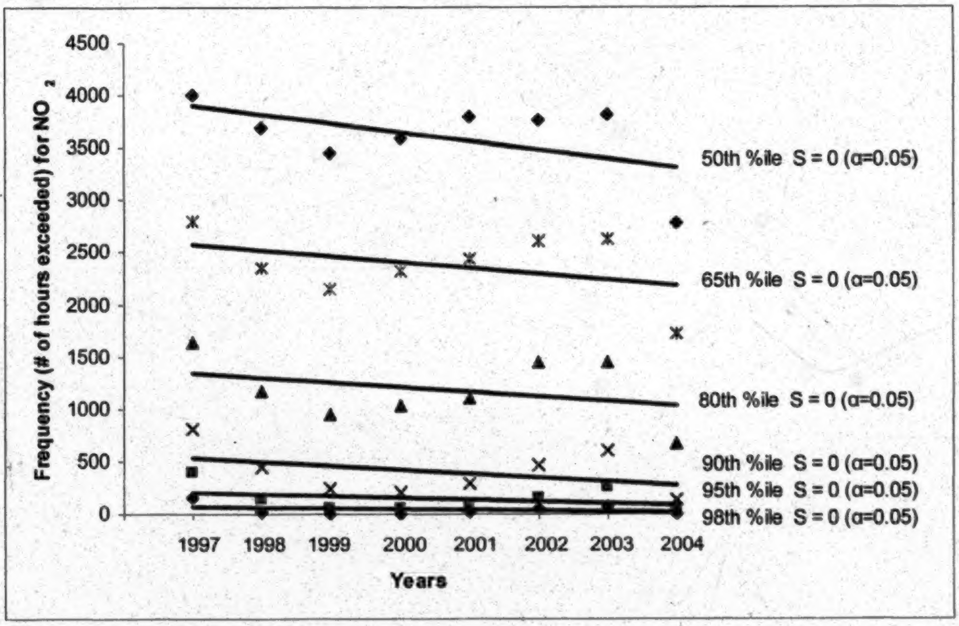

Figure 7-48: Edmonton Northwest air quality frequency trends for NO_2

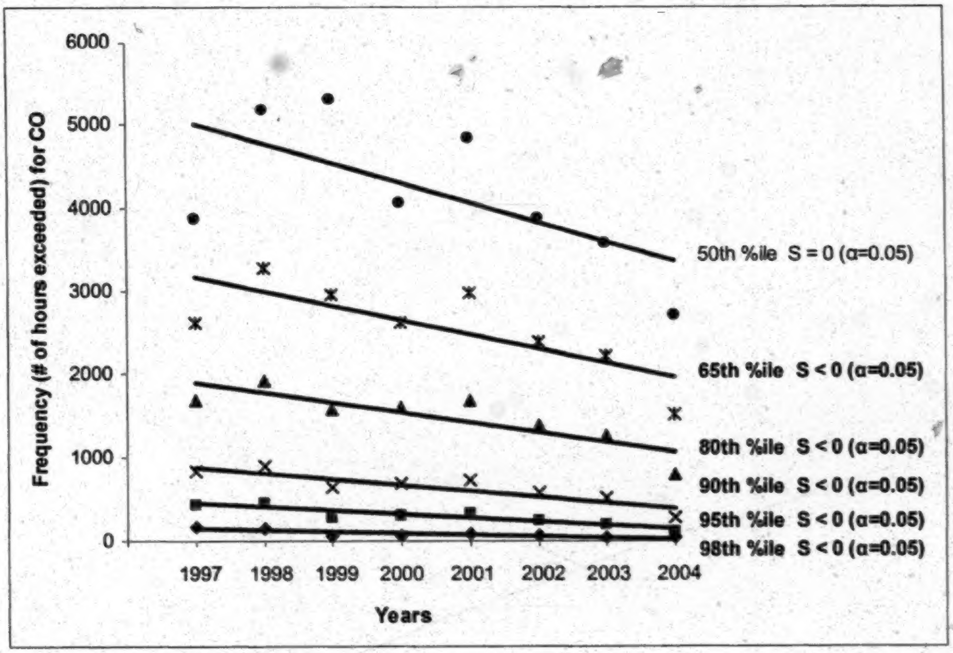

Figure 7-49: Edmonton Northwest air quality frequency trends for CO

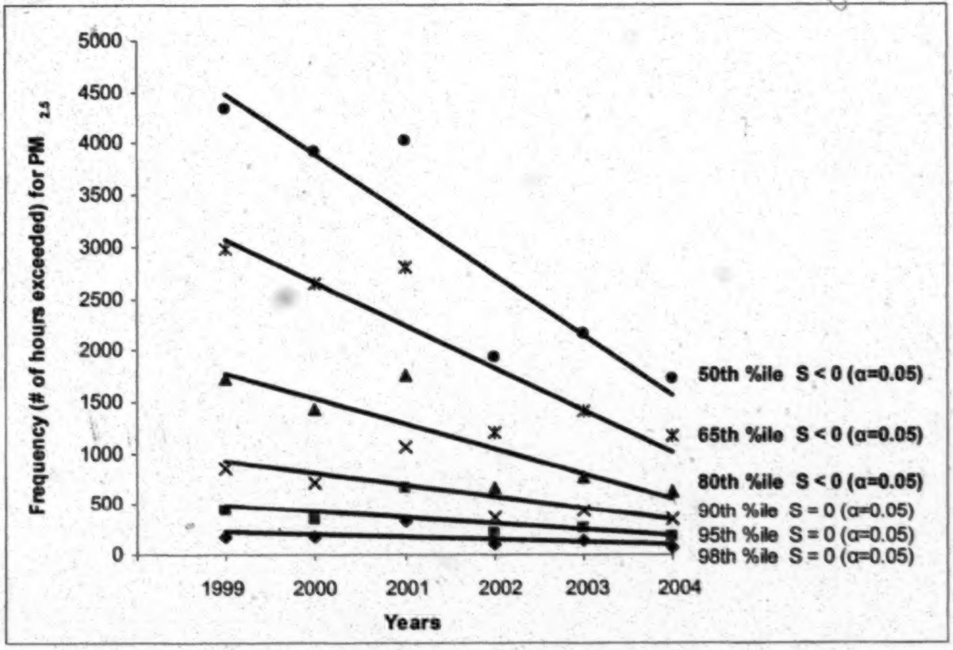

Figure 7-50: Edmonton Northwest air quality frequency trends for $PM_{2.5}$

APPENDIX 7.17 Frequency-based air quality trends for O_3, NO_2, $PM_{2.5}$ and THC – Fort McKay station

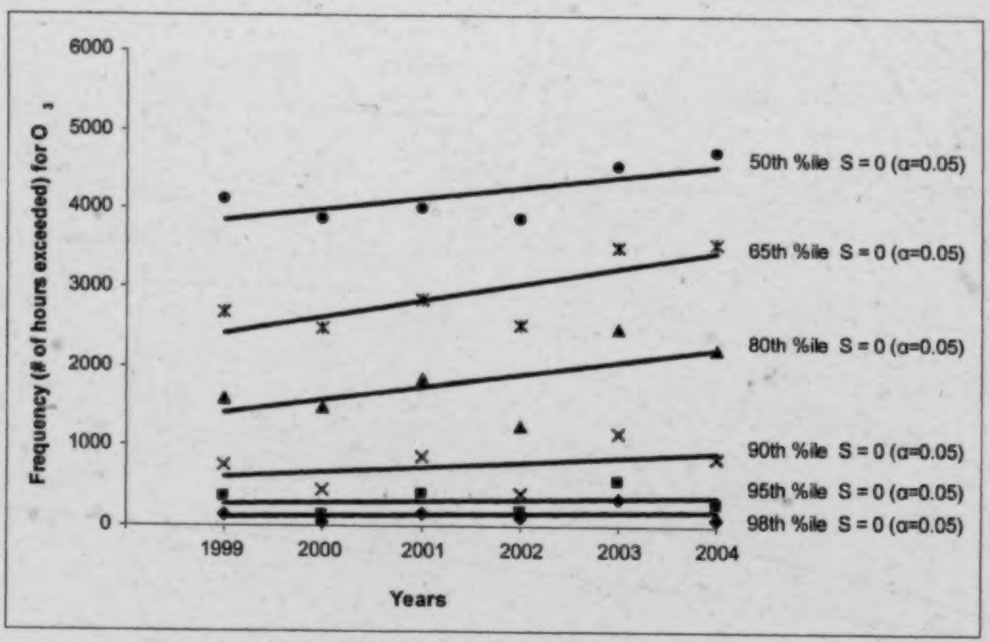

Figure 7-51: Fort McKay air quality frequency trends for O_3

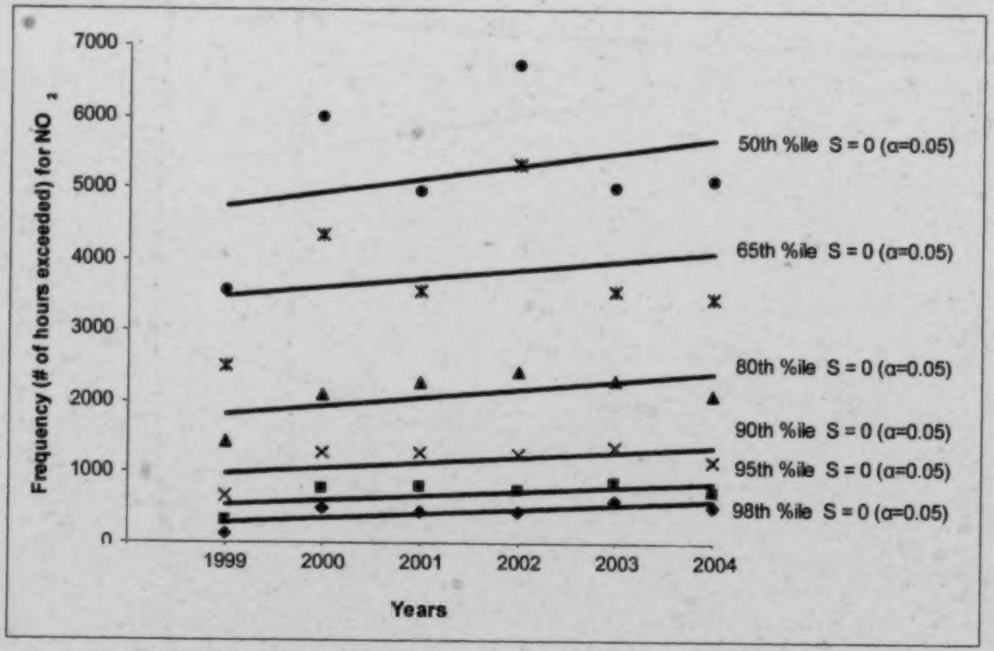

Figure 7-52: Fort McKay air quality frequency trends for NO_2

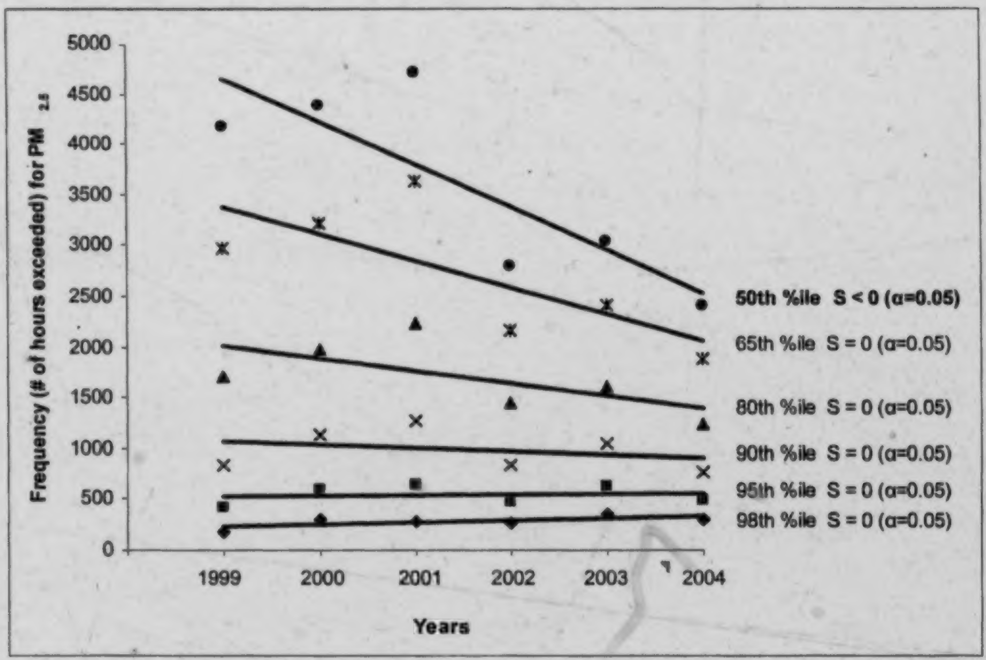

Figure 7- 53: Fort McKay air quality frequency trends for $PM_{2.5}$

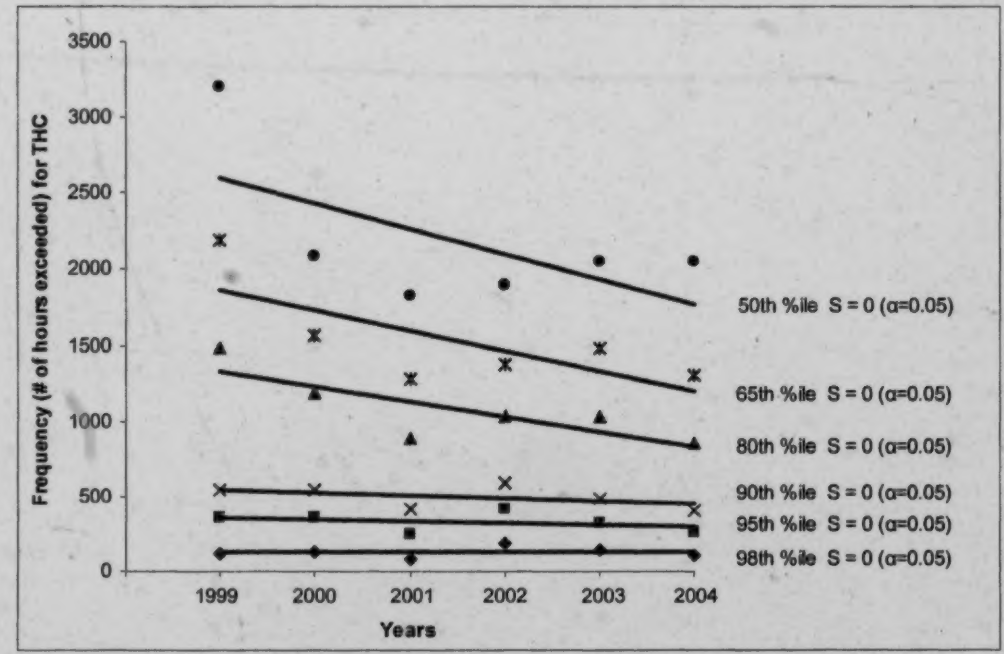

Figure 7- 54: Fort McKay air quality frequency trends for THC